STATE OF CALIFORNIA
BUSINESS, TRANSPORTATION AND HOUSING AGENCY
DEPARTMENT OF TRANSPORTATION

TRAFFIC MANUAL

CHAPTER 9
TRAFFIC SIGNALS AND LIGHTING

November, 2002

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Traffic Signals, Basic Information and Warrants 9-01

9-01.1 Introduction

A traffic signal is an electrically powered traffic control device, other than a barricade warning light or steady burning electric lamp, by which traffic is warned or directed to take some specific action.

The following types and uses of traffic signals are discussed in this chapter: Traffic Control Signals, Pedestrian Crossing Signals, Ramp Metering Signals, Flashing Beacons, Lane-use Control Signals, Traffic Control at Movable Bridges, Priority Control of Traffic Signals, Traffic Signals for One-lane, Two-way Facilities and Traffic Signals for Construction Zones.

Traffic control signals are devices for the control of vehicle and pedestrian traffic. They assign the right of way to the various traffic movements.

Traffic control signals have one or more of the following advantages:

1. They provide for the orderly movement of traffic.

2. They increase the traffic handling capacity of the intersection.

3. They reduce the frequency of certain types of accidents, especially the right angle type.

4. They can be coordinated to provide for continuous or nearly continuous movement of traffic at a definite speed.

5. They permit minor street traffic, vehicular or pedestrian, to enter or cross continuous traffic on the major street.

Experience shows that the number of right-angle collisions may decrease after the installation of signals, but the number of rear-end collisions may increase. The installation of signals may increase overall delay and reduce intersection capacity. Consequently, it is of the utmost importance that the consideration of a signal installation and the selection of equipment be preceded by a thorough study of traffic and roadway conditions made by an engineer experienced and trained in this field. Equally important is the need for checking the efficiency of a traffic signal in operation. This determines the degree to which the type of installation and the timing program meet the requirements of traffic.

9-01.2 Traffic Signal Warrants

The justification for the installation of a traffic signal at an intersection is based on the warrants stated in this Manual and in the Manual On Uniform Traffic Control Devices published by the Federal Highway Administration (FHWA). The decision to install a signal should not be based solely upon the warrants, since the installation of traffic signals may increase certain types of collisions. Delay, congestion, approach conditions, driver confusion, future land use or other evidence of the need for right of way assignment beyond that which could be provided by stop signs must be demonstrated. See Section 4-03 of this Manual for stop sign warrants.

When the 85th percentile speed of traffic on the major street exceeds 64 km/h in either an urban or rural area, or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the location is considered rural. All other areas are considered urban.

Figures 9-1, 9-2, 9-3 and 9-4 are examples of warrant sheets. Warrant Sheet 9-4 should be used only for new intersections or other locations where it is not reasonable to count actual traffic volumes.

The installation of a traffic signal should be considered if one or more of the warrants listed below are met:

A. Warrant 1 - Minimum Vehicle Volume.

The Minimum Vehicular Volume warrant is intended for application where the volume of intersecting traffic is the principal reason for consideration of a signal installation. The warrant is satisfied when for each of any 8 hours of an average day the traffic volumes given in the table below exist on the major street and on the higher-volume minor street approach to the intersection.

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)		Vehicles per hour on higher-volume minor-street approach (one direction only)	
Major St.	***Minor St.***	***Urban***	***Rural***	***Urban***	***Rural***
1	1	500	350	150	105
2 or more	1	600	420	150	105
2 or more	2 or more	600	420	200	140
1	2 or more	500	350	200	140

The major street and the minor street volumes are for the same 8 hours. During those 8 hours the direction of higher volume on the minor street may be on one approach during some hours and on the opposite approach during other hours.

B. Warrant 2 - Interruption of Continuous Traffic.

The Interruption of Continuous Traffic warrant applies to operating conditions where the traffic volume on a major street is so heavy that traffic on a minor intersecting street suffers excessive delay or hazard in entering or crossing the major street. The warrant is satisfied when, for each of any 8 hours of an average day, the traffic volumes given in the table below exist on the major street and on the higher-volume minor street approach to the intersection, and the signal installation will not seriously disrupt progressive traffic flow.

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)		Vehicles per hour on higher-volume minor-street approach (one direction only)	
Major St.	***Minor St.***	***Urban***	***Rural***	***Urban***	***Rural***
1	1	750	525	75	53
2 or more	1	900	630	75	53
2 or more	2 or more	900	630	100	70
1	2 or more	750	525	100	70

The major street and the minor street volumes are for the same 8 hours. During those 8 hours the direction of higher volume on the minor street may be on one approach during some hours and on the opposite approach during other hours.

C. Warrant 3 - Minimum Pedestrian Volume.

A traffic signal may be warranted where the pedestrian volume crossing the major street at an intersection or mid-block location during an average day is:

100 or more for each of any four hours; or

190 or more during any one hour.

The pedestrian volume crossing the major street may be reduced as much as 50% of the values given above when the predominant pedestrian crossing speed is below 1 m/s.

In addition to a minimum pedestrian volume of that stated above, there shall be less than 60 gaps per hour in the traffic stream of adequate length for pedestrians to cross during the same period when the pedestrian volume criterion is satisfied. Where there is a divided street having a median of sufficient width for the pedestrian(s) to wait, the requirement applies separately to each direction of vehicular traffic.

Where coordinated traffic signals on each side of the study location provide for platooned traffic which result in fewer than 60 gaps per hour of adequate length for the pedestrians to cross the street, a traffic signal may not be warranted.

This warrant applies only to those locations where the nearest traffic signal along the major street is greater than 90 m and where a new traffic signal at the study location would not unduly restrict platooned flow of traffic. Curbside parking at non-intersection locations should be prohibited for 30 m in advance of and 6 m beyond the crosswalk.

A signal installed under this warrant should be of the traffic-actuated type with push buttons for pedestrians crossing the main street. If such a signal is installed within a signal system, it shall be coordinated if the signal system is coordinated.

Signals installed according to this warrant shall be equipped with pedestrian indications conforming to requirements set forth in other sections of this Manual.

D. Warrant 4 - School Areas.

See Chapter 10 of this Manual.

E. Warrant 5 - Progressive Movement.

The Progressive Movement warrant is satisfied when:

1. On a one-way street or on a street which has predominantly unidirectional traffic, adjacent signals are so far apart that the necessary degree of platooning and speed control of vehicles would otherwise be lost; or

2. On a two-way street, where adjacent signals do not provide the necessary degree of platooning and speed control and the proposed and adjacent signals could constitute a progressive signal system.

The installation of a signal according to this warrant should be based on the 85th percentile speed unless an engineering study indicates that another speed is more desirable.

The installation of a signal according to this warrant should not be considered where the resultant signal spacing would be less than 300 m.

F. Warrant 6 - Accident Experience.

The Accident Experience warrant is satisfied when:

1. Five or more reported accidents of types susceptible to correction by traffic signal control have occurred within a 12-month period, each accident involving personal injury or property damage to an apparent extent of $500 or more; AND

2. Adequate trial of less restrictive remedies with satisfactory observance and enforcement has failed to reduce the accident frequency; AND

3. There exists a volume of vehicular traffic not less than 80% of the requirements specified in the Minimum Vehicular Volume Warrant or the Interruption of Continuous Traffic Warrant; AND

4. The signal installation will not seriously disrupt progressive traffic flow.

G. Warrant 7 - Systems Warrant.

A traffic signal installation at some intersections may be warranted to encourage concentration and organization of traffic flow networks. The systems warrant is applicable when the common intersection of two or more major routes has a total existing, or immediately projected, entering volume of at least 1,000 vehicles during the peak hour of a typical weekday, or each of any five hours of a Saturday and/or Sunday.

A major route as used in the above warrant has one or more of the following characteristics:

1. It is part of the street or highway system that serves as the principal network for through traffic flow;

2. It includes rural or suburban highways outside of, entering or traversing a city; or

3. It appears as a major route on an official plan such as a major street plan in an urban area traffic and transportation study.

H. Warrant 8 - Combination of Warrants.

In exceptional cases, a signal may be justified where no single warrant is satisfied but where Warrants 1 and 2 are satisfied to the extent of 80 percent or more of the stated numerical values.

I. Warrant 9 - Four Hour Volume Warrant.

The Four Hour Volume Warrant is satisfied, when for each of any four hours of an average day, the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the higher volume minor street approach(one direction only) all fall above the curve in Figure 9-6 for the existing combination of approach lanes.

When the 85th percentile speed of the major street traffic exceeds 64 km/h, or when the intersection lies within a built-up area of an isolated community having a population of less than 10,000, the four hour volume requirement is satisfied when the plotted points referred to fall above the curve in Figure 9-7 for the existing combination of approach lanes.

J. Warrant 10 - Peak Hour Delay Warrant.

The Peak Hour Delay Warrant is intended for application where traffic conditions are such that for one hour of the day, minor street traffic suffers undue delay in entering or crossing the major street. The peak hour delay warrant is satisfied when the conditions given below exist for one hour (any four consecutive 15-minute periods) of an average weekday. The peak hour delay warrant is met when:

1. The total delay experienced by traffic, on one minor street approach controlled by a STOP sign, equals or exceeds four vehicle-hours for a one-lane approach and five vehicle-hours for a two-lane approach; AND

2. The volume on the same minor street approach equals or exceeds 100 vph for one moving lane of traffic or 150 vph for two moving lanes; AND

3. The total entering volume serviced during the hour equals or exceeds 800 vph for intersections with four or more approaches or 650 vph for intersections with three approaches.

K. Warrant 11 - Peak Hour Volume Warrant.

The Peak Hour Volume Warrant is intended for application where traffic conditions are such that for one hour of the day minor street traffic suffers undue delay in entering or crossing the major street.

The peak hour volume warrant is satisfied when the plotted point, representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the higher volume minor street approach (one direction only) for one hour (any four consecutive 15-minute periods) of an average day, falls above the curve in Figure 9-8 for the existing combination of approach lanes.

When the 85th percentile speed of major street traffic exceeds 64 km/h, or when the intersection lies within a built-up area of an isolated community having a population of less than 10,000, the peak hour volume warrant is satisfied when the plotted point, referred to above, falls above the curve in Figure 9-9 for the existing combination of approach lanes.

9-01.3 Guidelines for Left-Turn Phases

Since separate signal phases for protected left turns will reduce the green time available for other phases, alternate means of handling left turn conflicts should be considered first.

The most likely possibilities are:

1. Prohibition of left turns. This can be done only if there are convenient alternate means of making the movement. Typical alternate means are:

   a. A series of right and/or left turns around a block to permit getting to the desired destination; or

   b. Making the left turn at an adjacent unsignalized intersection during gaps in the opposing through traffic.

2. Geometric changes to eliminate the left turn. An effective change would be a complete separation or a complete or partial "clover leaf" at grade. Any of these, while eliminating left turns, requires additional cost and right of way.

3. Provide protected-permissive or permissive-protected left turn operation. The protected left turn interval may be prohibited during certain periods of the day to allow only permissive intervals for left turn movement in order to increase the green time available for other phases. Refer to Section 9-03.8 for the requirements of protected-permissive or permissive-protected left turn operation.

Protected left turn phases should be considered where such alternatives cannot be utilized, and one or more of the following conditions exist:

1. ***Accidents.*** Five or more left turn accidents for a particular left turn movement during a recent 12-month period.

2. ***Delay.*** Left-turn delay of one or more vehicles which were waiting at the beginning of the green interval and are still remaining in the left turn lane after at least 80% of the total number of cycles for one hour.

3. ***Volume.*** At new intersections where only estimated volumes are available, the following criteria may be used. For a

pretimed signal or a background-cycle-controlled actuated signal, a left turn volume of more than two vehicles per approach per cycle for a peak hour; or for a traffic-actuated signal, 50 or more left turning vehicles per hour in one direction with the product of the turning and conflicting through traffic during the peak hour of 100,000 or more.

4. *Miscellaneous.* Other factors that might be considered, include but are not limited to: impaired sight distance due to horizontal or vertical curvature, or where there is a large percentage of buses and trucks.

9-01.4 Removal of Existing Signals

Changes in traffic patterns may result in a situation where a traffic signal is no longer justified. When this occurs, consideration should be given to removing the traffic signal and replacing it with appropriate alternative traffic control devices.

9-01.5 Bicycle Signals

A bicycle signal is an electrically powered traffic control device that may only be used in combination with an existing traffic signal. Bicycle signals shall direct bicyclists to take specific actions and may be used to address an identified safety or operational problem involving bicycles.

When bicycle traffic is controlled, only green, yellow and red lighted bicycle symbols, shall be used to implement bicycle movement at a signalized intersection. The application of bicycle signals shall be implemented only at locations that meet Department of Transportation Bicycle Signal Warrants. This will remain in effect until January 1, 2005.

A separate signal phase for bicycle movement will be used. Alternative means of handling conflicts between bicycles and motor vehicles shall be considered first. Two alternatives that should be considered are:

1. Striping to direct a bicyclist to a lane adjacent to a traffic lane such as a bike lane to the left of a right-turn-only lane.

2. Redesigning the intersection to direct a bicyclist from an off-street path to a bicycle lane at a point removed from the signalized intersection.

A bicycle signal phase will be considered only after these and other less restrictive remedies have had an adequate trial with enforcement and with the result that the collision frequency has not been reduced.

Bicycle Signal Warrant

A bicycle signal may be considered for use only when the volume and collision or volume and geometric warrants have been met:

1. *Volume*. When $W = B \times V$ and $W \geq 50{,}000$ and $B \geq 50$.

   Where: W is the volume warrant.
   B is the number of bicycles at the peak hour entering the intersection.
   V is the number of vehicles at the peak hour entering the intersection.
   B and V shall use the same peak hour.

2. *Collision*. When 2 or more bicycle/vehicle collisions of types susceptible to correction by a bicycle signal have occurred over a 12-month period and the responsible public works official determines that a bicycle signal will reduce the number of collisions.

3. *Geometric*. (a) Where a separate bicycle/multi use path intersects a roadway. (b) At other locations to facilitate a bicycle movement that is not permitted for a motor vehicle.

Figure 9-1
TRAFFIC SIGNAL WARRANTS

DIST _____ CO _____ RTE _____ KPM _____

CALC _____ DATE _____
CHK _____ DATE _____

Major St: _____ Critical Approach Speed _____ km/h
Minor St: _____ Critical Approach Speed _____ km/h

Critical speed of major street traffic > 64 km/h ☐
or ☐ } **RURAL (R)**
In built up area of isolated community of < 10,000 pop. ☐ **URBAN (U)**

WARRANT 1 - Minimum Vehicular Volume

100% SATISFIED **YES** ☐ **NO** ☐
80% SATISFIED **YES** ☐ **NO** ☐

	MINIMUM REQUIREMENTS (80% SHOWN IN BRACKETS)									
	U	R	U	R						
APPROACH LANES	1		2 or more							Hour
Both Apprchs. Major Street	500 (400)	350 (280)	600 (480)	420 (336)						
Highest Apprch. Minor Street	150 (120)	105 (84)	200 (160)	140 (112)						

WARRANT 2 - Interruption of Continuous Traffic

100% SATISFIED **YES** ☐ **NO** ☐
80% SATISFIED **YES** ☐ **NO** ☐

	MINIMUM REQUIREMENTS (80% SHOWN IN BRACKETS)									
	U	R	U	R						
APPROACH LANES	1		2 or more							Hour
Both Apprchs. Major Street	750 (600)	525 (420)	900 (720)	630 (504)						
Highest Apprch. Minor Street	75 (60)	53 (42)	100 (80)	70 (56)						

WARRANT 3 - Minimum Pedestrian Volume

100% SATISFIED **YES** ☐ **NO** ☐

REQUIREMENT	FULFILLED
Pedestrian volume crossing the major street is 100 or more for each of any four hours or is 190 or more during any one hour; AND	Yes ☐ No ☐
There are less than 60 gaps per hour in the major street traffic stream of adequate length for pedestrians to cross; AND	Yes ☐ No ☐
The nearest traffic signal along the major street is greater than 90 m; AND	Yes ☐ No ☐
The new traffic signal will not seriously disrupt progressive traffic flow on the major street.	Yes ☐ No ☐

The satisfaction of a warrant is not necessarily justification for a signal. Delay, congestion, confusion or other evidence of the need for right-of-way assignment must be shown.

Figure 9-2
TRAFFIC SIGNAL WARRANTS

WARRANT 4 - School Areas

Not Applicable ☐
See School Protection Warrants Sheet ☐

WARRANT 5 - Progressive Movement **SATISFIED** **YES** ☐ **NO** ☐

MINIMUM REQUIREMENTS	DISTANCE TO NEAREST SIGNAL	FULFILLED
> 300 m	N_____m, S_____m, E_____m, W_____m.	YES ☐ NO ☐
ON ONE WAY ISOLATED STREETS OR STREETS WITH ONE WAY TRAFFIC SIGNIFICANCE AND ADJACENT SIGNALS ARE SO FAR APART THAT NECESSARY PLATOONING & SPEED CONTROL WOULD BE LOST		
ON 2-WAY STREETS WHERE ADJACENT SIGNALS DO NOT PROVIDE NECESSARY PLATOONING AND SPEED CONTROL PROPOSED SIGNALS COULD CONSTITUTE A PROGRESSIVE SIGNAL SYSTEM		☐ ☐

WARRANT 6 - Accident Experience **SATISFIED** **YES** ☐ **NO** ☐

REQUIREMENTS	WARRANT	✓	FULFILLED
ONE WARRANT SATISFIED 80%	WARRANT 1 - MINIMUM VEHICULAR VOLUME		
	OR WARRANT 2 - INTERRUPTION OF CONTINUOUS TRAFFIC		YES ☐ NO ☐
SIGNAL WILL NOT SERIOUSLY DISRUPT PROGRESSIVE TRAFFIC FLOW			☐ ☐
ADEQUATE TRIAL OF LESS RESTRICTIVE REMEDIES HAS FAILED TO REDUCE ACCIDENT FREQUENCY			☐ ☐
ACC. WITHIN A 12 MONTH PERIOD SUSCEPTIBLE OF CORR. & INVOLVING INJURY OR ≥ $500 DAMAGE			
MINIMUM REQUIREMENT	NUMBER OF ACCIDENTS		
5 OR MORE			☐ ☐

WARRANT 7 - Systems Warrant **SATISFIED** **YES** ☐ **NO** ☐

MINIMUM VOLUME REQUIREMENT	ENTERING VOLUMES - ALL APPROACHES	✓	FULFILLED
1000 VEH/HR	DURING TYPICAL WEEKDAY PEAK HOUR_____VEH/HR		
	OR DURING EACH OF ANY 5 HRS. OF A SAT. AND/OR SUN. _____VEH/HR		YES ☐ NO ☐

CHARACTERISTICS OF MAJOR ROUTES	MAJOR ST.	MINOR ST.	
HWY. SYSTEM SERVING AS PRINCIPAL NETWORK FOR THROUGH TRAFFIC			
RURAL OF SUBURBAN HWY OUTSIDE OF, ENTERING, OR TRAVERSING A CITY			
APPEARS AS MAJOR ROUTE ONAN OFFICIAL PLAN			
ANY MAJOR ROUTE CHARACTERISTICS MET, BOTH STREETS			☐ ☐

The satisfaction of a warrant is not necessarily justification for a signal. Delay, congestion, confusion or other evidence of the need for right-of-way assignment must be shown.

Figure 9-3
TRAFFIC SIGNAL WARRANTS

WARRANT 8 - Combination of Warrants **SATISFIED** **YES** ☐ **NO** ☐

REQUIREMENT	WARRANT	✓	FULFILLED
TWO WARRANTS SATISFIED 80%	1. MINIMUM VEHICULAR VOLUME		YES ☐ NO ☐
	2. INTERRUPTION OF CONTINUOUS TRAFFIC		

WARRANT 9 - Four Hour Volume **SATISFIED*** **YES** ☐ **NO** ☐

Approach Lanes	One	2 or more					Hour
Both Approaches - Major Street							
Highest Approaches - Minor Street							

* Refer to Figure 9-6 (URBAN AREAS) or Figure 9-7 (RURAL AREAS) to determine if this warrant is satisfied.

WARRANT 10 - Peak Hour Delay **SATISFIED** **YES** ☐ **NO** ☐

(ALL PARTS MUST BE SATISFIED)

1. The total delay experienced for traffic on one minor street approach controlled by a STOP sign equals or exceeds four vehicle-hours for a one-lane approach and five vehicle-hours for a two-lane approach; AND **YES** ☐ **NO** ☐
2. The volume on the same minor street approach equals or exceeds 100 vph for one moving lane of traffic or 150 vph for two moving lanes; AND **YES** ☐ **NO** ☐
3. The total entering volume serviced during the hour equals or exceeds 800 vph for intersections with four or more approaches or 650 vph for intersections with three approaches. **YES** ☐ **NO** ☐

WARRANT 11- Peak Hour Volume **SATISFIED*** **YES** ☐ **NO** ☐

Approach Lanes	One	2 or more					Hour
Both Approaches - Major Street							
Highest Approaches - Minor Street							

* Refer to Figure 9-8 (URBAN AREAS) or Figure 9-9 (RURAL AREAS) to determine if this warrant is satisfied.

The satisfaction of a warrant is not necessarily justification for a signal. Delay, congestion, confusion or other evidence of the need for a right-of-way assignment must be shown.

Figure 9-4
TRAFFIC SIGNAL WARRANTS

(Based on Estimated Average Daily Traffic - See Note)

URBAN ---------- RURAL ----------	Minimum Requirements EADT	
1. Minimum Vehicular Satisfied _____ Not Satisfied _____	Vehicles per day on major street (total of both approaches)	Vehicles per day on higher-volume minor street approach (one direction only)
Number of lanes for moving traffic on each approach Major Street / Minor Street 1 / 1 2 or more / 1 2 or more / 2 or more 1 / 2 or more	Urban / Rural 8,000 / 5,600 9,600 / 6,720 9,600 / 6,720 8,000 / 5,600	Urban / Rural 2,400 / 1,680 2,400 / 1,680 3,200 / 2,240 3,200 / 2,240
2. Interruption of Continuous Traffic Satisfied _____ Not Satisfied _____	Vehicles per day on major street (total of both approaches)	Vehicles per day on higher-volume minor street approach (one direction only)
Number of lanes for moving traffic on each approach Major Street / Minor Street 1 / 1 2 or more / 1 2 or more / 2 or more 1 / 2 or more	Urban / Rural 12,000 / 8,400 14,400 / 10,080 14,400 / 10,080 12,000 / 8,400	Urban / Rural 1,200 / 850 1,200 / 850 1,600 / 1,120 1,600 / 1,120
3. Combination Satisfied _____ Not Satisfied _____ No one warrant satisfied, but following warrants fulfilled 80% or more ..... _____ (1) _____ (2)	2 Warrants	2 Warrants

NOTE: To be used only for NEW INTERSECTIONS or other locations where it is not reasonable to count actual traffic volumes.

Figure 9-5
SCHOOL PROTECTION WARRANTS

DIST _____ CO _____ RTE _____ KPM _____

CALC _____ DATE _____
CHK _____ DATE _____

Major St: _____ Critical Approach Speed _____ km/h
Minor St: _____ Critical Approach Speed _____ km/h

Critical speed of major street traffic > 64 km/h ☐
or } **RURAL (R)**
In built up area of isolated community of < 10,000 pop. ☐ **URBAN (U)**

FLASHING YELLOW SCHOOL SIGNALS

(ALL PARTS MUST BE SATISFIED)

SATISFIED YES ☐ NO ☐

PART A

	Minimum Requirements	U	R
Vehicle Volume	Each of 2 hours	200	140
School Age Pedestrians Crossing Street	Each of 2 hours	40	40

SATISFIED YES ☐ NO ☐

AND

PART B

Critical Approach Speed Exceeds 56 km/h

SATISFIED YES ☐ NO ☐

AND

PART C

Is nearest controlled crossing **more than** 180 m away?

SATISFIED YES ☐ NO ☐

SCHOOL AREA TRAFFIC SIGNALS

(ALL PARTS MUST BE SATISFIED)

SATISFIED YES ☐ NO ☐

PART A

	Minimum Requirements	U	R
Vehicle Volume	Each of 2 hours	500	350
School Age Pedestrians Crossing Street	Each of 2 hours	100	70
	or per day	500	350

SATISFIED YES ☐ NO ☐

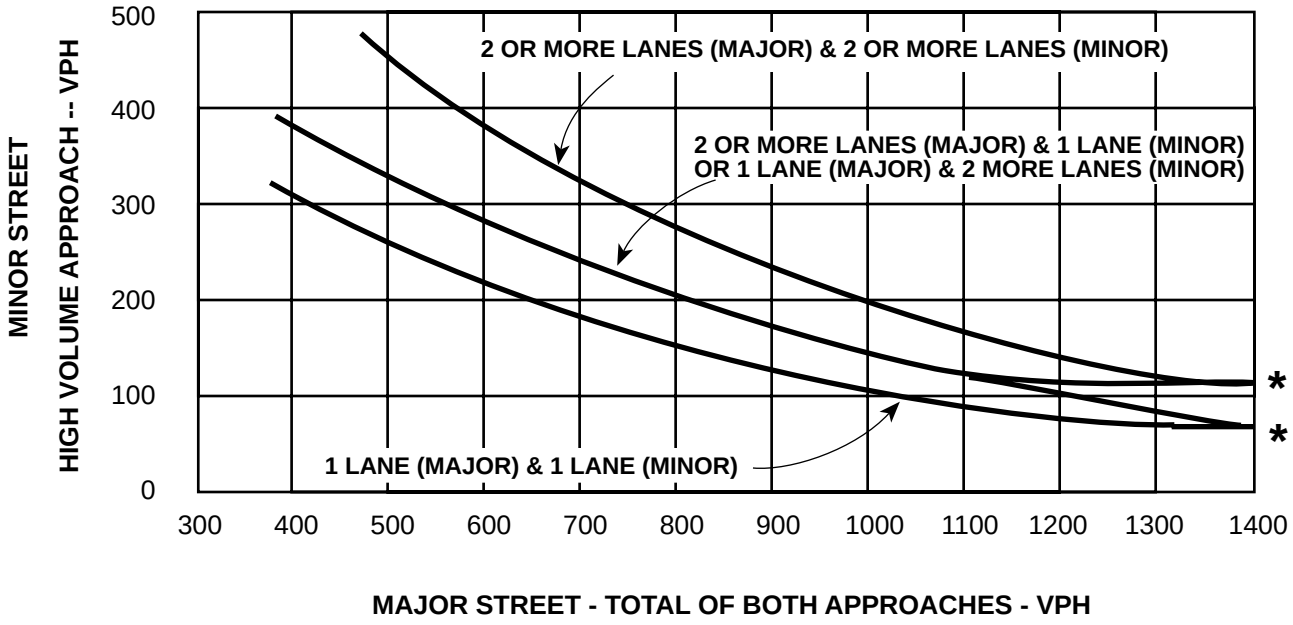
AND

PART B

Is nearest controlled crossing **more than** 180 m away?

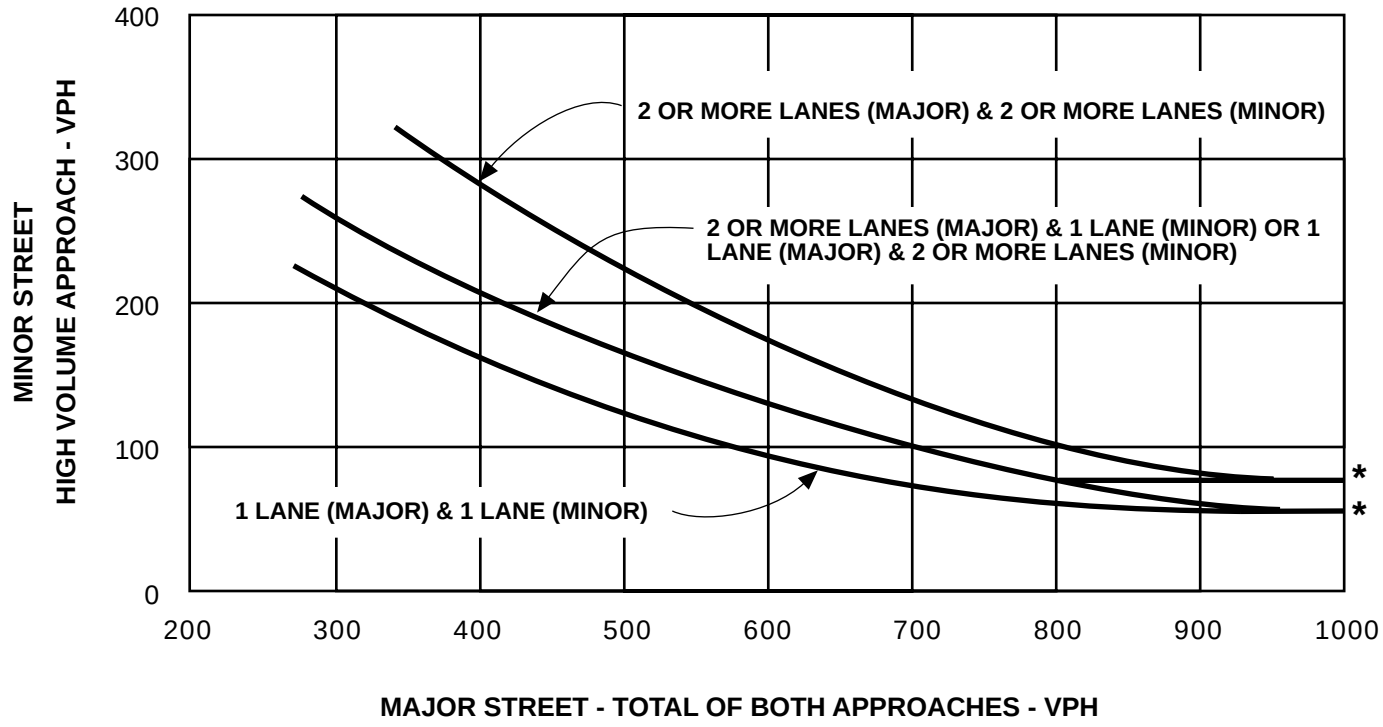
SATISFIED YES ☐ NO ☐

Figure 9-6
FOUR HOUR VOLUME WARRANT
(Urban Areas)



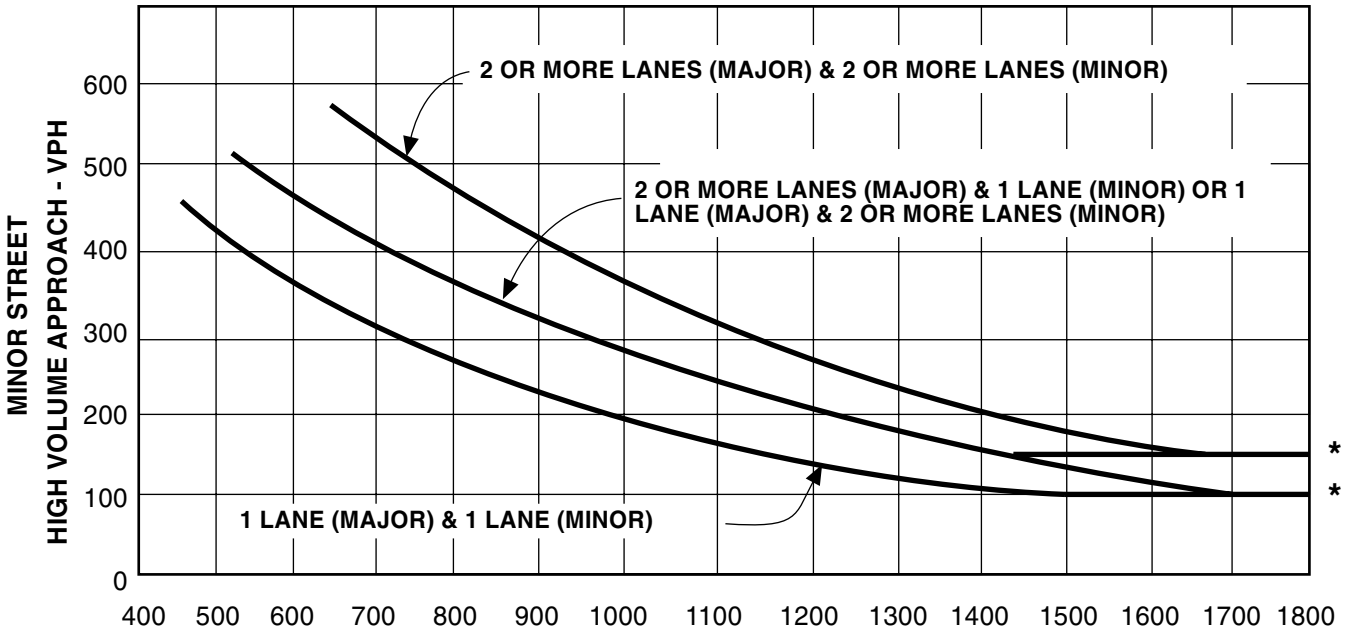
*** NOTE:**
115 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR STREET APPROACH WITH TWO OR MORE LANES AND 80 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR STREET APPROACHING WITH ONE LANE.

Figure 9-7
FOUR HOUR VOLUME WARRANT
(Rural Areas)



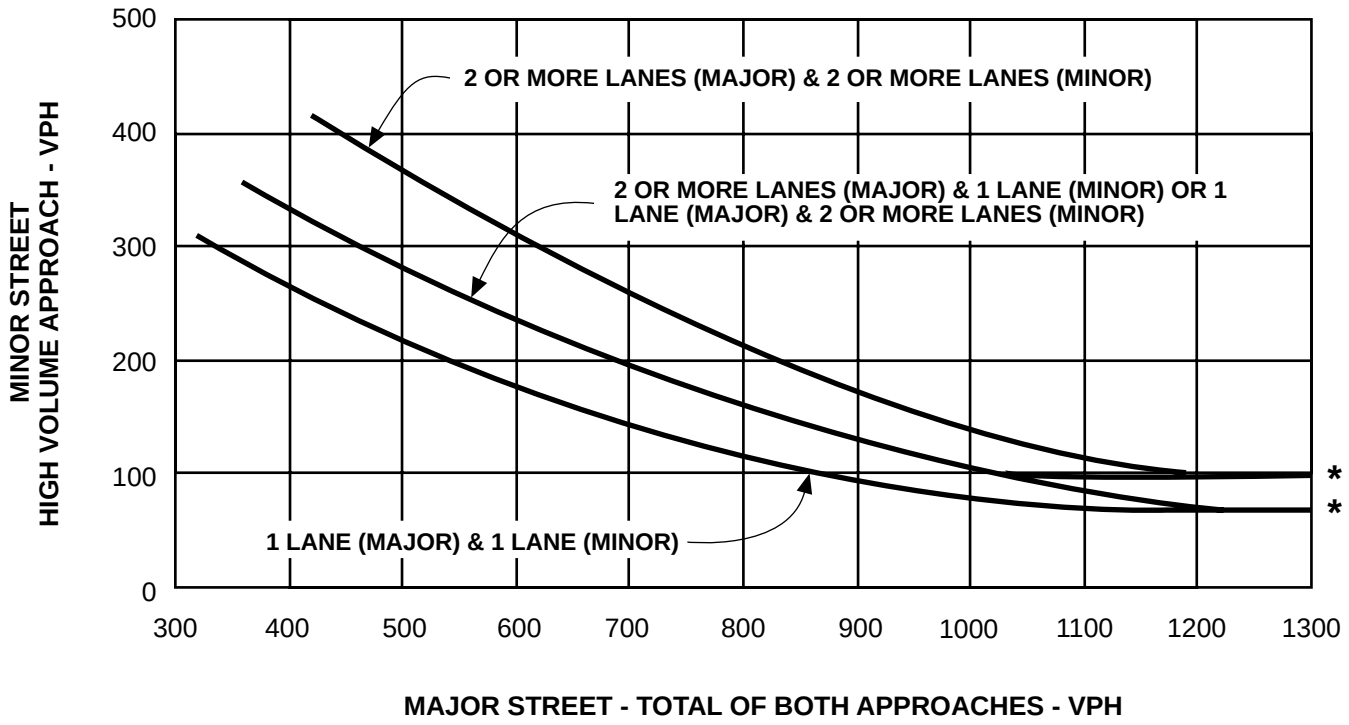
*** NOTE:**
80 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR STREET APPROACH WITH TWO OR MORE LANES AND 60 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR STREET APPROACHING WITH ONE LANE.

Figure 9-8
PEAK HOUR VOLUME WARRANT
(Urban Areas)



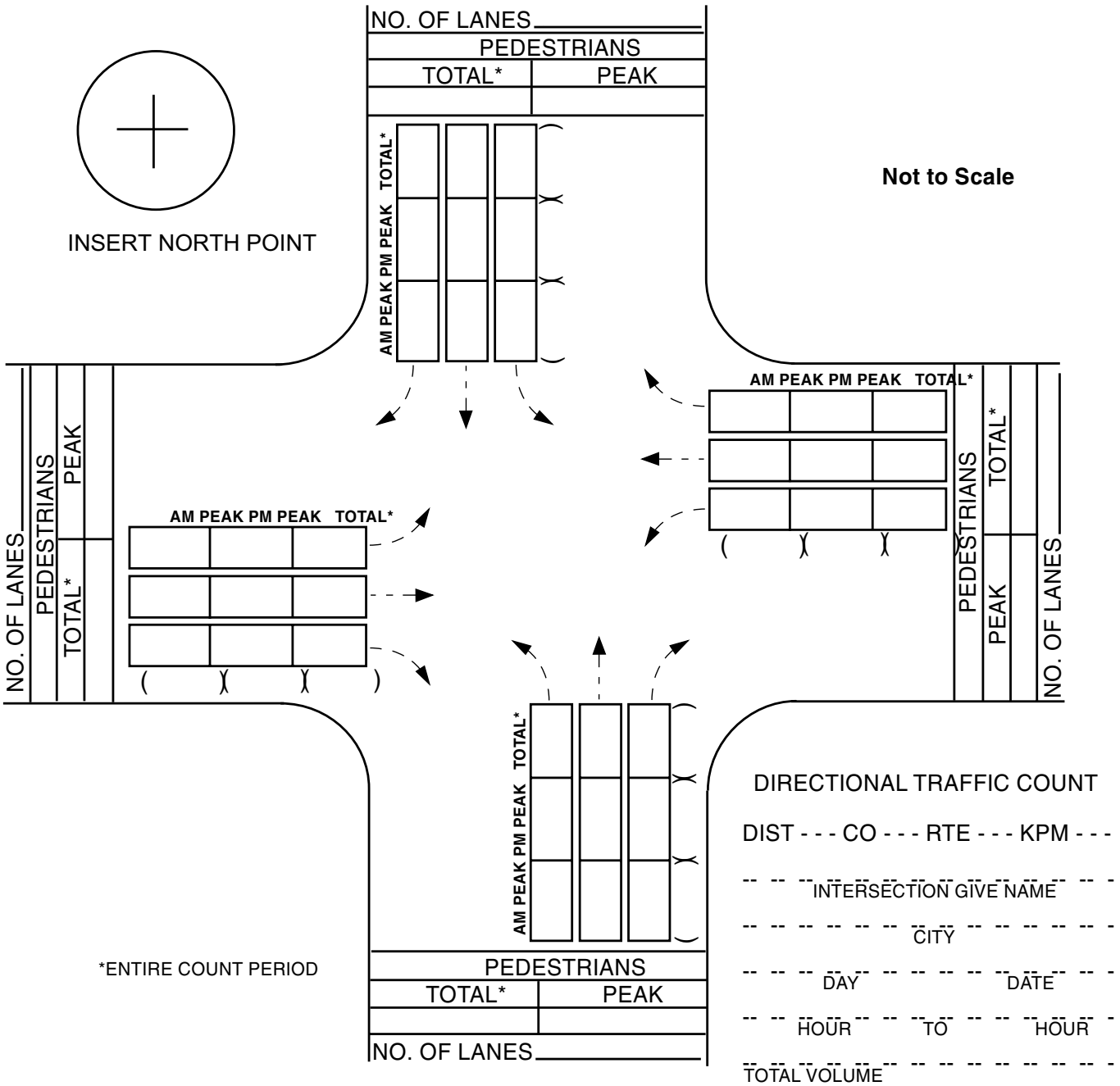
* NOTE:
150 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR STREET APPROACH WITH TWO OR MORE LANES AND 100 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR STREET APPROACHING WITH ONE LANE.

Figure 9-9
PEAK HOUR VOLUME WARRANT
(Rural Areas)



* **NOTE:**
100 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR STREET APPROACH WITH TWO OR MORE LANES AND 75 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR STREET APPROACHING WITH ONE LANE.

Figure 9-10
DIRECTIONAL TRAFFIC COUNT SHEET



Traffic Signal Development Procedures 9-02

9-02.1 Introduction

General requirements for the development of traffic signal, lighting and electrical systems projects are noted in the Project Development Procedures Manual. The cost of traffic signals on Federal Aid highway projects is eligible for federal participation under certain conditions.

The preparation of a Project Study Report may be required for major traffic signal lighting and/or electrical system projects for scoping and programming purposes. The Project Development Procedures Manual and the appropriate Program Advisor should be consulted to determine specific reporting requirements.

9-02.2 Project Report

The District shall prepare a project report of the investigation of conditions at locations where a new traffic signal is to be installed, an existing traffic signal is to be modified or an existing traffic signal is to be removed. District Directors are authorized to approve project reports in accordance with the current Departmental policies contained in the Project Development Procedures Manual. Three copies of the District-approved project report shall be forwarded to the Chief, State and Local Project Development. A project report shall be prepared whether the work is performed by the State or by others.

General requirements for project reports are noted in the Project Development Procedures Manual. A project report for the installation, modification (except for upgrading projects involving specific equipment) or removal of a traffic signal should include the following specific information:

1. ***Traffic Counts.***

   Both pedestrian and vehicular traffic counts should include the periods of the average day when the signals would appear to be needed most. The counts should be at least eight hours in duration, not necessarily consecutive, but including a.m. and p.m. peak hours.

   Traffic counts for a new signal shall be shown on appropriate Traffic Signal Warrant Sheets and a Directional Traffic Count Sheet.

   Where pedestrian volumes are significant, show the volume on each crosswalk for the same periods as the vehicle count.

   When estimated traffic volumes are used in establishing traffic signal warrants, they should be prepared on Form TS-10D. See Figure 9-4.

2. ***Collision Diagram.***

   A collision diagram for the intersection covering the recent accident experience history. The diagram should cover a 3-year interval.

3. ***Condition Diagram.***

   A condition diagram showing existing roadway conditions. Any railroad grade crossing within 60 m of the intersection should be shown.

4. ***Improvement Diagram.***

   A diagram showing existing and proposed signals, phasing, channelization and other proposed improvements. This may be combined with 1, 2 and/or 3 on a single plan.

5. ***Estimate.***

   An estimate of the cost of the project(including State furnished materials) and the proposed method of financing.

6. ***Other Specialized Data When Appropriate:***

   a. Classification of Vehicles. The classification is required when it is a significant factor in affecting intersection capacity.

   b. Critical Speed (85th percentile) of Approaching Vehicles. This is the speed at a point unaffected by existing controls.

   c. Time-Space Diagram. When the project involves a coordinated traffic signal system.

9-02.3 PS&E Submittals

General requirements for the submittal of plans, specifications and estimates are noted in the Project Development Procedures Manual and the PS&E Guide. All electrical plans shall bear the following: "Note: This plan accurate for electrical work only."

9-02.4 Financing

Unless previously budgeted, the financing of a project is considered only after receipt of the PS&E Report and cooperative agreements.

Normally, the costs of a new traffic signal or the modification of a signal or signal system are to be shared with a local agency. In situations where a new traffic signal or a modification to an existing traffic signal or traffic signal system is urgently needed to improve safety or traffic flow on the State highway and the local agencies are unable to finance their prorated share of the cost, the State may accept a lesser participation, or even no participation, by the local authorities. The definition of "urgently needed" shall be made by the District Director.

The cost of small projects such as modifications to existing traffic signals(detectors, signal heads, mast arms, etc.) where the prorated share of the local agency is $3,000 or less, shall be at 100% State expense.

9-02.5 Design Cost

The following criteria shall apply in determining the amount of participation in the design cost by the State and a local agency.

Where the State prepares plans for the installation or modification of a traffic signal or a traffic signal system on a State highway, the design costs should be shared with the local agency.

Where the local agency is to prepare the plans, the State may participate in the design costs. Participation should be the same as construction cost participation and be covered by a cooperative agreement.

Estimated design costs should be determined on the basis of an agreed fixed percentage of the total project costs. The fixed percentage should be based on historical design costs for projects in the price range concerned.

Where the State is requested by a local agency to prepare plans and specifications for a traffic signal project that does not involve State participation in the construction costs, the design costs shall be borne entirely by the local agency or others. The State may, however, assume the design engineering costs and the construction engineering costs, where the local agency agrees to pay all of the construction costs for a warranted project and where all of the costs would normally be shared on a prorated basis.

9-02.6 Construction Costs - Conventional Highways

The following criteria shall apply in determining the amount of the construction costs by the State and local agency for a traffic signal, safety lighting, channelization or widening project on conventional State highways.

Channelization and/or Widening Costs. On cooperatively financed projects, the channelization and/or widening costs shall be shared as follows:

1. Channelization on and/or widening of the State highway shall be at 100% State expense.

2. Channelization on and/or widening of the local street shall be at 100% local agency expense.

3. Where the local agency's portion of the channelization or widening is a minor part of the channelization or widening being constructed by the State and the local agency's share of the work amounts to $3,000, or less, the State may assume the entire cost of the channelization or widening.

Channelization and/or widening required as a part of the conditions of a permit by a private party shall be at 100% expense of the private party.

In Cases A, B, and D listed below, the costs of constructing the electrical facilities are to be shared by the State and local agencies. The costs shall be shared on a prorated basis in the same ratio as the number of legs in the intersection under each agency's jurisdiction bears to the total number of legs.

Case A. Installation or Modification of a Traffic Signal and/or Safety Lighting at an Existing Intersection.

When a traffic signal and/or safety lighting is to be installed or modified at the intersection of a State highway and a local road, local agency participation in the installation or modification costs shall be sought.

Case B. Existing Driveways at Existing Signalized Intersections.

A private driveway that constitutes a leg at an existing signalized intersection should be treated as follows:

1. If the driveway does not generate appreciable traffic, no control is required.

2. If the driveway serves an area that generates sufficient traffic to constitute a problem, it should be controlled. One example of control is the use of a red flashing beacon and/or an R41 RIGHT TURN ONLY sign to control egress from the private driveway. Another would be to provide signal indications for the private driveway.

3. Costs shall be as in Case D.

Case C. A New Road or Driveway at an Existing Signalized Intersection.

Where a new road or driveway is to be constructed to enter an existing "T" intersection, the cost of necessary right-of-way, traffic signal and/or safety lighting shall be at 100% local agency or permittee expense. The cost shall include the signal faces and detectors for the new approach and signal faces

and detectors for left turns into the new approach and channelization, if necessary.

Case D. Installation of a Traffic Signal and/or Safety Lighting at an existing intersection with a Driveway.

Where a traffic signal and/or safety lighting is to be installed at an existing intersection serving an area which generates sufficient traffic to constitute a problem that includes a private driveway as the fourth approach, the cost of signal and lighting equipment for the driveway approach shall be included in the cost of the entire installation.

Where one or more legs of the intersection are under the jurisdiction of a local agency, the construction costs shall be shared with the local agency. The cost of the driveway leg shall be included with the local agency's share. It shall be the responsibility of the local agency to obtain the right-of-way, right-of-entry or easement necessary to install and maintain the signal equipment to be located on private property.

Case E. Reconstruction of a Conventional State Highway.

When it is necessary to widen or reconstruct a State highway, the reconstruction and relocation of traffic control devices and safety lighting systems, shall be at 100% State expense. Local participation for purposes of expediting a project should be accepted.

Additional traffic control devices installed in connection with reconstruction of a conventional highway are to be treated as in Case A.

Case F. Relocation of a Conventional State Highway.

When an existing State highway is relocated, the State will install warranted traffic control devices and safety lighting at State expense. Local participation will not be required. If, however, a local authority wishes to participate in a project in order to expedite it, local participation should be accepted.

Case G. Installation of a Traffic Signal and/or Safety Lighting at a Private Driveway or Privately Owned Street.

The cost of a new traffic signal and/or safety lighting installed at a private driveway or privately owned street (i.e., not under the jurisdiction of a city or county) shall be entirely at the expense of the property owner or developer.

The permittee shall grant the State access rights to the private property at any time for the purpose of maintaining or timing the signal and lighting.

Upon installation, all rights, title and interest in the traffic signal equipment shall be granted to the State by the permittee. In the event that the State finds it advisable for the signals to be removed, the State will remove and salvage the equipment.

Case H. Reconstruction of Existing Facilities.

When affected by State highway construction, existing street lighting, police and fire alarm systems, and similar systems owned by a city, county or publicly owned service district shall be relocated at the sole expense of the owner, unless prior rights can be established.

Case I. School Traffic Signals and Flashing Beacons.

Where traffic signals and/or flashing beacons are justified only by the School Area Traffic Signal Warrant on a State highway (see Chapter 10), the installation shall be at 100% State expense. When any other warrant is met also, the cost is shared in the usual manner.

9-02.7 Construction Costs - Freeways

The installation of electrical work and channelization at an intersection of a freeway ramp and a local road shall be at 100% State expense if such improvements are warranted at the time the freeway is to be opened to traffic, or if they are estimated to be warranted within five years after the date the freeway is opened to traffic.

It may be difficult to accurately predict the traffic pattern at interchanges at the time of the freeway design. Therefore, the need for signals at the ramp connections to local roads cannot always be anticipated. If within five years after the date of completion of the freeway, the interchange does not operate in the manner intended, and signal warrants are met, it will be the policy to provide signals, lighting, channelization or roadway widening as necessary to facilitate the flow of traffic through the interchange. This work is to be done entirely at State expense in the same manner as it would have been done had it been planned in the original freeway project. This includes widening of roadway approaches to proposed signalized ramp intersections in accordance with present design practice entirely at State expense. Approval by local agencies must be obtained for changes to roads under their jurisdiction.

After the five-year period, the cost of installation shall be financed in the same manner as for existing intersections. In lieu of treating each ramp intersection individually and sharing the costs on the basis of the number of legs under each jurisdiction, the concept of the overall facility as described in the Maintenance Manual may be used.

Frontage roads or portions of frontage roads which serve as connections between ramps to or from the freeway and existing public roads and which are retained under State jurisdiction shall be considered as freeway ramps and electrical work at the intersections shall be financed as described above.

Any time the interchange is revised by adding or relocating ramps, it is considered a new interchange and the cost of signals at the ramp terminals and/or the connection to the local road shall be at 100% State expense.

9-02.8 Roadway Improvements by Local Agencies

Any new connection of a local street to a State highway, including any electrical work, widening and/or channelization required within the State highway right of way, shall be at 100% local agency expense.

At existing intersections any relocation or improvement of electrical facilities due to widening and/or channelization of the local street shall be at 100% local agency expense.

9-02.9 Cooperative Agreements

When a local agency participates in the various project costs, a cooperative agreement is required. Each agreement shall include a statement of ownership, maintenance and operation. Preapproved agreement forms and procedure details are available.

9-02.10 Engineering Services for Local Agencies

Contracts with local agencies for the State to provide traffic signal control system engineering services shall include a clause relating to "Legal Relationships and Responsibilities". Preapproved wording is available.

9-02.11 Salvaged Electrical Equipment

A construction project sometimes includes the removal of traffic signal, lighting or other electrical equipment that is not to be reused on the particular project. The determination as to whether particular electrical equipment is salvable will be made at the District level. The determination as to whether or not to salvage existing equipment should be made on the basis of the economic benefit to the State and on the conservation of energy and/or materials that would result from salvaging and/or reinstallation. Equipment should be salvaged if it falls within one of the following categories:

1. It is an item for which there is a foreseeable use.

2. It is part of an electrical installation owned jointly with another agency and the other agency has requested the salvaged equipment.

3. It is usable in some other District.

4. It can be immediately disposed of by other means.

All electrical equipment removed and determined not to be salvable shall become the property of the contractor.

Equipment determined to be salvable shall be disposed of as follows:

1. If the electrical installation is jointly owned by the State and one or more local agencies, each of the owners shall share in the salvage value. The local agencies shall be given first choice in obtaining the salvaged equipment. The agency obtaining the salvaged equipment shall reimburse the other agency in accordance with the proportionate ownerships.

2. Where the State or local agency is replacing existing electrical equipment without the other agency participating in the cost of the new equipment, the salvaged equipment shall belong to the party or parties who bore the cost of the new equipment unless otherwise specified in an agreement or encroachment permit.

The salvage value shall be determined at the District level during preparation of the preliminary report. The salvage value should be such that if the equipment were taken into State storage it could be used economically for maintenance or as State-furnished material on contracts. The estimated salvage value should make the equipment more attractive to local agencies than the money representing the other partner's share of the salvage value. Wire and wiring supplies such as conduit, junction boxes, and connectors, and other materials should be considered as a lot at no value, or in any case, not more than the nominal sum of $1.

Often, salvaged electrical equipment is available for use on new installations; in many cases this will result in considerable savings.

9-02.12 Encroachment Permits

Encroachment permits are required for a local agency or a private party to install or modify traffic signals and street lighting on a State highway. Plans and Specifications prepared by Permittee's should conform to State Standard Specifications, Standard Plans and be submitted to the District for review and approval. In each case, a statement of ownership, maintenance and operation shall be included in the permit.

A Permit Engineering Evaluation Report (PEER) may be prepared in lieu of a project report for all projects estimated to cost $1,000,000 or less, as part of the encroachment permit review process. Instructions for PEER's are found in the Project Development Procedures Manual and the Encroachment Permits Manual.

All projects financed, in whole or in part, from retail transactions and use taxes and projects costing more than $1,000,000 require a cooperative agreement.

Traffic Signal Design 9-03

9-03.1 Introduction

The design of traffic signals by the California Department of Transportation (Caltrans) is based upon the following publications:

1. Traffic Manual (Caltrans)
2. Standard Specifications (Caltrans)
3. Standard Plans (Caltrans)
4. Signal and Lighting Design Guide (Caltrans)
5. Ramp Meter Design Guidelines (Caltrans)
6. Highway Design Manual (Caltrans)
7. Manual on Uniform Traffic Control Devices for Streets and Highways (FHWA)

Additional references that may be used include:

1. Transportation and Traffic Engineering Handbook, Institute of Traffic Engineers (ITE)
2. Manual of Traffic Signal Design (ITE)
3. Traffic Control Systems Handbook (FHWA)
4. Traffic Control Systems Standards, National Electrical Manufacturers Association (NEMA)
5. Traffic Control Devices Handbook (FHWA)

9-03.2 Selection of Traffic Signal Operation

A prime factor to be considered in selection of the type of traffic signal operation is adequacy. While it may be true that a sophisticated signalcontrol will operate satisfactorily at any intersection, the intersection should not be provided with a type of control that is unnecessarily complex and expensive.

The type of traffic signal operation to be used is dependent upon the variations in traffic demand. The two general types of signal operation are pretimed and traffic-actuated. Traffic-actuated operation can be further classified as full-traffic-actuated or semi-traffic-actuated. With full-traffic-actuated operation, all traffic movements or phases are provided with detectors. In semi-traffic-actuated operation, certain phases (usually the coordinated phases) do not have detectors.

Pretimed and semi-traffic-actuated operation should be used in coordinated systems only. They should not be installed at isolated intersections (more than 1.6 km from the closest signalized intersection).

Where the distance between signalized intersections is 0.8 km or less, coordination of signals should be considered, including the preparation of a time-space diagram and an evaluation of the cost-effectiveness of coordination.

Discretion should be used with phasing at offset intersections as it may introduce operational problems which should be recognized and avoided. The most critical of these problems is where one approach right-of-way is terminated while the opposing approach continues with a green indication.

9-03.3 Selection of Left-Turn Phasing

There are various methods to signalize left turn movements. See Figure 9-11.

If the left turn volume is 300 or more vehicles per hour, or if delays to traffic at the intersection can be significantly reduced, consideration should be given to a two-lane left turn.

9-03.4 Simultaneous or Dual Left

This method is most effective during free or isolated operation and is traffic-actuated. It is the most efficient means of providing protected left turn movements since the various phases and combinations of phases appear only on demand. A through movement is allowed to go with its associated left turn movement when there is no opposing left turn traffic.

9-03.5 Lead-Lag

This operation can be either pretimed or traffic-actuated.

Normally, "Lead-Lag" phasing should be considered for coordinated signals when the offset timing determined by the system time-space diagram results in the arrival of the two directions of traffic at different times during a cycle. This will provide the most efficient progressive band.

9-03.6 Opposite or Opposing

Opposing operation should be used where the left turn volume per lane is very high in either direction and is about equal to or greater than the companion through movement. This method is especially useful when one of the through lanes must be used as an optional turning lane or where a separate left turn lane cannot be provided.

9-03.7 Three Phase Operation

Three phase operation can be either pretimed or traffic-actuated.

9-03.8 Permissive Left-Turn Phasing

This type of operation allows vehicles to make left turns during a fully-protected interval with a green arrow indication, or to make a permissive left turn with a circular green indication when there are adequate gaps in opposing traffic. Permissive left turn phasing may be either pre-timed or traffic actuated. Examples of the operation may be found in the Traffic Control Devices Handbook (FHWA).

There are normally two sequences that can be utilized with permissive left turn phasing:

1. *Protected-Permissive.*

   With this operation, left turn traffic is first directed to turn left on the display of a green arrow and then permitted to turn during the nonprotected interval on the display of a circular green.

2. *Permissive-Protected.*

   With this operation, the left turn traffic is first permitted to turn during the nonprotected interval on the display of a circular green and then directed to turn left on the display of a green arrow.

The advantages of this operation when compared to fully-protected left turn phasing only are:

1. Reduces delay as left turn drivers may have an opportunity to make their left turns during the green interval or yellow change interval for through traffic.

2. Allows the use of shorter cycle lengths in coordinated systems by reducing the time of the fully protected green interval for the left turn movement.

3. Less chance of disrupting traffic in adjacent through lanes as left turn queues are less likely to exceed the length of the left turn lane.

When a protected-permissive or permissive-protected left-turn phasing operation is used for a signal system on a State highway, no information sign is necessary. If a sign is used, it shall be a R73-7, LEFT TURN YIELD ON GREEN (Green Ball symbol) sign on State highways.

Public agencies having jurisdiction may use an extinguishable message sign on local roads in place of the R73-7, on their local roads that are not part of an intersection with a State highway. The message shall say LEFT TURN YIELD in at least 150 mm high letters. The light source shall be designed and constructed so that when illuminated, the message shall be white and remain dark when not in use. The message shall be illuminated only when the green permissive ball is lighted.

The following shall apply to permissive left-turn phasing:

1. This operation shall not be initiated where the left turn accident warrant is satisfied.

2. Signal faces should not be placed in a median facing a left turn lane.

3. Signs are not required for this operation unless U-turns are to be prohibited.

4. Both directions of through traffic shall be terminated simultaneously except where opposing left turns or opposing U-turns are prohibited.

9-03.9 Location of Controller Cabinets

Normally, controller cabinets should be located in accordance with the following:

1. It should not be vulnerable to traffic.

2. Traffic movements at the intersection should be visible from the controller timing position.

3. The doors of the cabinet should open away from the curb or traveled way.

4. It should be possible to park a maintenance truck close to the cabinet.

5. It should not be located in a drainage ditch, in an area which could be under water or where subjected to water from sprinklers.

6. It should not obstruct sidewalks, wheelchair ramps, or store entrances.

7. It should be placed so as not to obstruct pedestrian or driver visibility.

Upon requests, keys for the police panel on traffic signal controller cabinets shall be furnished to the California Highway Patrol offices or local enforcement agencies.

9-03.10 Vehicle Signal Faces and Indications

Arrangement of vehicle signal faces shall conform to the Manual on Uniform Traffic Control Devices (FHWA). Normally, each vehicle signal face will consist of at least three sections. Some of the exceptions are that a single section with a green arrow lens may be used to indicate a continuous movement and a 2-section (red, green) face may be used for ramp metering.

Signal lenses shall be a minimum of 200 mm in diameter. Arrow indications and flashing beacons (except those used in ramp metering) shall have lenses 300 mm in diameter. Mast arm mounted, span-wire mounted and signal bridge mounted indications should have lenses 300 mm in diameter.

9-03.11 Number of Signal Faces

There shall be at least two signal faces for each controlled approach of an intersection including signalized left turn lanes.

Supplemental signal faces should be considered if any of the following conditions exist:

1. The area is rural.

2. The area is urban and the signal is the first one on a particular highway.

3. The roadway is striped for two or more approach lanes.

4. Where visibility of the signal is affected by alignment or obstructions.

9-03.12 Location of Signal Faces

On an undivided roadway, the signal faces for each through approach of an intersection are usually placed at the far right and far left corners. The signal faces for two or more approaches can often be combined on a single standard. However, is generally desirable to locate the signal faces on separate standards at curb returns. This practice will tend to maximize the visibility of the signal faces for the controlled approach while minimizing the visibility of the signal faces intended for the cross-street approach. It may be necessary to locate signal faces on separate standards whenever the curb return radius is greater than 3 m. Where additional signal faces are required, they may be suspended from a mast arm.

The preferred locations for new installations of signal faces for fully-protected left turn movements at a typical intersection are on a mast arm of sufficient length to place one signal face as nearly as practical in the center of the left turn lane and to place the second face on a standard at the far left corner. Unusual roadway geometrics, wide medians, wide roadways, more than one left turn lane in the same direction or other factors may require the left turn signal face(s) to be mounted on standard(s) located in a median to satisfy visibility requirements.

A signal face, containing a circular green indication, may be located in a far median only when:

1. The signal phasing provides a protected left turn movement; or

2. The signal face is provided with some type of visibility control so that the indications are not visible to traffic in the left turn storage lane; or

3. It is not facing a left turn storage lane.

A signal face containing a circular green indication may be located in the near median where there is a left turn storage lane and there is no associated left turn phase.

Supplemental signal faces may be placed at a near side location or suspended from a mast arm.

9-03.13 Arrow Indications

A green arrow indication shall be used only to allow vehicular movements which are completely protected from conflict with other vehicles moving on a green indication or with pedestrians crossing in conformance with a walk interval or pedestrian clearance interval.

A red arrow indication shall be used only in a separate signal face which also contains yellow arrow and green arrow indications. A red arrow indication may be used where it is desired to prohibit right-turn-on-red or left-turn-on-red.

9-03.14 Left-Turn Arrows

A left-turn green arrow indicates that a left-turn may be made without conflict from opposing traffic. Normally, protected only left-turn phasing requires the use of three-section signal faces. The sections should have lenses as follows: red arrow, yellow arrow and green arrow.

Protected-permissive or permissive-protected (with full-traffic-actuated operation) left-turn phasing requires the use of five-section signal faces. Normally the far left sections should be arranged vertically. See "m" in Figure 4-1 of the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD). The mast arm indication shall be arranged in cluster or stacked ("s" or "m" in Figure 4-1 of the MUTCD). The five sections shall have lenses as follows: circular red, circular yellow, circular green, yellow arrow and green arrow. The cluster or stack arrangement shall not be used for protected only left-turn phasing.

9-03.15 Right-Turn Arrows

The right-turn green arrow indicates that traffic may make the indicated right-turn without conflict from opposing traffic. It is usually displayed simultaneously with a circular red, circular yellow, or circular green indication or another green arrow indication.

When a right-turn green arrow is to be displayed during the nonconflicting left-turn green interval of the cross street, the U-turn on the cross street shall be prohibited.

A right-turn green arrow should be considered for use only when there is an exclusive right-turn lane or it is the only movement that traffic is permitted to make or when the right-turn volume exceeds 200 vehicles per hour.

A right-turn yellow arrow shall be shown following a right turn green arrow when a circular red or a right-turn red arrow is to follow.

9-03.16 Vertical Green Arrows

A vertical green arrow indicates that traffic may proceed straight through an intersection but shall not turn right or left. It shall not be displayed simultaneously in the same face with a circular red.

9-03.17 Mounting Heights - Vehicle Signal Faces

The bottom of bracket mounted and post-top mounted vehicle signal faces, including left turn signal faces on the far left corner, should be not less than 3 m above the roadway, sidewalk or median grade.

Mounting heights for vehicle signal faces are shown in the Standard Plans.

9-03.18 Signal Face Visibility Control

It is always desirable to limit the visibility of specific signal indications to only those drivers and pedestrians that they are intended to regulate. Some visibility control is provided by proper positioning of a signal face to:

1. Assist mechanical light control devices such as louvers or visors; and

2. Associate the indication with the controlled traffic movement.

However, there are instances where additional visibility control is required. Applications of such control may be classified into lateral (lane or approach) separation and longitudinal (distance) separation.

Examples of conditions where lateral separation should be considered are:

1. Adjacent parallel roadways; and

2. Acute angle intersections.

Examples of conditions where longitudinal separation should be considered are:

1. Closely-spaced intersections;

2. Offset intersections; and

3. Intersections with wide medians.

Devices available for limiting or controlling signal indication visibility include louvers, programmed visibility signal sections, and long visors.

Programmed visibility signal sections can provide either lateral or longitudinal separation. Typical locations or conditions in which they should be considered are at adjacent signalized intersections that are 90 m or less apart or at intersections angled at less than 45 degrees. In order that programmed visibility signal faces function properly, it is important that they be properly located relative to the approach lanes they are intended to control. The proper relationship is available from the manufacturer.

9-03.19 Backplates

Backplates should be installed on all mast arm mounted signal faces, all far median left turn signals, all far right signal faces, and on those signal faces that are in front of a background that could be confused with or could distract from the signal.

9-03.20 Pedestrian Signal Faces

Signal design must provide for or prohibit pedestrian movements. Pedestrians are better controlled by pedestrian signal faces rather than vehicular signal faces. This is because pedestrian signal faces used with appropriate pedestrian timing intervals provide adequate crossing and clearance times and in addition reduce the possibility of pedestrians unnecessarily blocking the intersection by entering a crosswalk near the end of a vehicle green interval.

Pedestrian signal faces should be installed under the conditions listed in Section 4D-3 of the MUTCD.

9-03.21 Types of Pedestrian Signal Faces

Pedestrian signal faces at new signal installations on State highways shall be the international symbol type as shown in the MUTCD, i.e., the WALKING PERSON and the upraised HAND.

Existing "WALK - WAIT" signal faces may continue to be kept in operation. However, they should be replaced as a part of a major modernization project.

9-03.22 Mounting Height - Pedestrian Signal Faces

The bottom of the housing for a pedestrian signal face should be not less than 2.1 m, nor more than 3.0 m, above the sidewalk grade.

9-03.23 Detectors

The proper operation of a traffic-actuated signal is dependent upon the appropriate type and proper placement of vehicle and pedestrian detectors.

9-03.24 Vehicle Detectors

The types and applications of vehicle detectors currently used include the following:

1. *Inductive Loop.*

   The inductive loop detector, because of its presence feature, detects a standing vehicle as well as a moving one. The detection area is roughly that enclosed by the loop.

2. *Magnetometer.*

   The magnetometer detector detects a standing vehicle, as well as a moving one, and has a detection area up to 1 m in diameter over each sensing element.

3. *Magnetic.*

   The magnetic detector detects only vehicles moving in excess of 8 km/h. One sensing element covers one or two traffic lanes.

4. *Pressure-Sensitive.*

   No new installations are to be made. Existing units shall be replaced with loop, magnetometer or magnetic types when:

   a. They require relocation;

   b. The traffic signal is to be modified; or

   c. The roadway is to be resurfaced.

5. *Video Detection.*

   Video detection detects vehicles passing through the field of view of a CCTV camera or image sensor. They are useful during construction or other temporary situations when lanes change frequently in width and location as well as where the installation of conduit and detector loops is expensive or difficult. Care is necessary to avoid locations and conditions which could obscure the detector's visibility such as extreme weather, sun glare and moving shadows.

The normal installation of inductive loop and magnetometer detectors requires sound pavement if the detector is to operate reliably. If the pavement on an approach in which these detectors are to be installed is cracked, the project should include resurfacing of the areas where the detectors and lead-in cables are to be placed. Typical installation details for inductive loop and magnetometer detectors are shown on the Standard Plans.

The longitudinal location (setback) of detectors relative to the limit line depends on the speed of traffic and the type of detector operation desired. Suggested setbacks are shown in Table 9-1.

9-03.25 Pedestrian Detectors

Where required, pedestrian push buttons should be located convenient to the corresponding crosswalk so as to encourage their use by both pedestrians and people in wheelchairs. Push buttons should be located not more than 1.5 m from the crosswalk and should be placed on signal poles if they are adjacent to the crosswalk area. Separate pedestrian push-button posts should be used when the signal poles are more than 1.5 m from the crosswalk.

9-03.26 Bicycle Detectors

Bicycle detectors may be required at traffic-actuated signal installations.

A Type D loop configuration shown on Standard Plan ES-5B is effective for detecting bicycles and small motorcycles and shall be installed at the bicycle loop detector locations. Loop detectors shall not be placed within a pedestrian crosswalk or where it could conflict with pedestrian traffic.

The loop detector logo shown on Standard Plan A24C may be used to show a bicyclist where to stop in a bike lane or traffic lane to be detected. The logo should be applied to the pavement in the center of the Type D loop.

See Figure 9-12 for suggested locations of bicycle detectors and the Standard Plans for typical bike lane pavement markings.

9-03.27 Signal Plan Schedules

The traffic signal plans for the installation of a new signal or the major modification of an existing signal should include the following schedules:

1. Pole and Equipment Schedule.

   A pole and equipment schedule shows the types of standards, mast arm lengths, types and mounting for vehicle and pedestrian signal faces, and other equipment. See Figure 9-23 and the Standard Plans.

2. Conductors and Conduit Schedule.

   A conductor and conduit schedule shows the size of each conduit run, and the size, type and number of conductors or cables in each conduit run. See Figure 9-24.

Dimensions of conductors and conduit and data for determining conduit size are shown in Tables 9-8 and 9-9.

9-03.28 Preemption

At some signal locations, it is necessary to preempt the normal traffic signal operation by a railroad train, an emergency vehicle or bus/transit vehicles.

The order of priority for various types of preemption shall be:

1. Railroad
2. Emergency Vehicle
3. Bus/Transit Vehicles

9-03.29 Railroad Preemption

Railroad preemption results in a special traffic signal operation depending on the relation of the railroad tracks to the intersection, the number of phases in the traffic signal and other traffic conditions. Railroad preemption is normally controlled by the railroad grade crossing warning equipment.

Typical circumstances where railroad preemption is required and the type of signal operation to be provided during preemption are as follows:

1. Where a railroad grade crossing, provided with grade crossing warning equipment, is within 60 m of a signalized intersection, preemption of the traffic signal should provide the following sequence of operation:

   a. A yellow change interval and any required red clearance interval for any signal phase that is green or yellow when preemption is initiated and which will be red during the track clearance interval. The length of yellow change and red clearance intervals shall not be altered by preemption. Phases which are in the green interval when preemption is initiated, and which will be green during the track clearance interval, shall remain green. Any pedestrian walk or clearance interval, in effect when preemption is initiated, shall immediately be terminated and all pedestrian signal faces shall display steady DONT WALK or upraised HAND.

   b. A track clearance interval for the signal phase or phases controlling the approach which crosses the railroad tracks. The signal indication for the clearance interval may be either green or flashing red.

   c. A yellow change interval if green signal indications were provided during the track clearance interval.

   d. Depending on traffic requirements and phasing of the traffic signal controller, the traffic signal may then do one of the following:

(1) Go into flashing operation, with flashing red or flashing yellow indications for the approaches parallel to the railroad tracks and flashing red indications for all other approaches. Pedestrian signals shall be extinguished. If flashing red is used for all approaches, an all-red or other clearance interval shall be provided prior to returning to normal operation.

(2) Revert to limited operation with those signal indications controlling through and left turn approaches towards the railroad tracks displaying steady red. Permitted pedestrian signal phases shall operate normally. This operation shall be used only if the grade crossing warning equipment includes gates.

e. The traffic signal shall return to normal operation following release of preemption control.

2. Where the railroad tracks run within a roadway and train speeds exceed 16 km/h, preemption of the traffic signal should provide the following sequence of operation.

a. A yellow change interval and any required red clearance interval for all signal phases that are green or yellow when preemption is initiated and which will be red during the preemption period. The length of yellow change and red clearance intervals shall not be altered by preemption. Phases which are in the green interval when preemption is initiated and which will be green during the preemption period, shall remain green. Any walk or pedestrian clearance intervals in effect when preemption is initiated shall be immediately terminated and all pedestrian signal faces shall display DONT WALK or upraised HAND.

b. All signal faces controlling traffic movements parallel to the railroad tracks will display green or flashing yellow indications. All other vehicle signal faces will display red indications; pedestrian signal faces will display DONT WALK or upraised HAND.

3. Where the railroad tracks run along a roadway of a signalized intersection and train speeds do not exceed 16 km/h, trains may be controlled by the vehicle signal indications. This type of train control requires approval from the railroad, the Public Utilities Commission and the Director of Transportation.

4. Unusual or unique track or roadway configurations may require other solutions than those described above.

9-03.30 Emergency Vehicle Preemption

Traffic signals on State highways may be preempted by authorized emergency vehicles. The purpose of such preemption is to provide the right of way to the emergency vehicle as soon as practical. The preemption may be controlled by one of the following means:

1. By direct wire, modulated light or radio from a remote location such as a fire house; and

2. By modulated light or radio from an emergency vehicle.

Emergency vehicle preemption should provide the following sequence of operation:

1. A yellow change interval and any required red clearance interval for any signal phase that is green or yellow when preemption is initiated and which will be red during the preemption interval. The length of the yellow change and red clearance intervals shall not be altered by preemption. Phases which are in the green interval when preemption is initiated and which will be green during the preemption period shall remain green. Any pedestrian walk interval in effect when preemption is initiated shall be immediately terminated. The normal pedestrian clearance interval may be abbreviated.

2. An all-red intersection preemption display shall not be used.

3. The traffic signal shall return to normal operation upon termination of the demand for preemption or the termination of the assured green interval.

At a traffic signal provided with both emergency vehicle preemption and railroad preemption, the railroad preemption shall have priority. In the event of a demand for an emergency vehicle preemption during the time that the intersection is operating on railroad preemption, the railroad preemption sequence shall continue unaffected until completion. In the event of a demand for railroad preemption during emergency vehicle preemption operation, railroad preemption shall immediately assume control of the intersection.

When control of emergency vehicle preemption is by means of a radio or modulated light source, the following shall apply:

1. The transmitter shall be permanently mounted on the emergency vehicle or building and shall operate at a range sufficient to permit a normal yellow change interval and any required clearance intervals to take place prior to the arrival of the emergency vehicle. The normal pedestrian clearance interval may be abbreviated.

2. The preemption system may provide an indication (such as a special signal) to the driver of an emergency vehicle that preemption of the traffic signal has been effected. If a special signal light is used, the color shall not be red, yellow, or green.

3. The system shall be designed to prevent simultaneous preemption by two or more emergency vehicles on separate approaches to the intersection.

When performed by a local agency, the installation of emergency vehicle preemption equipment shall be covered by an Encroachment Permit issued by the District Director. The permit shall state the applicable requirements from those listed above and the following:

1. It should be understood that the permit for the installation may be revoked or changed as deemed advisable or necessary by Caltrans.

2. The timing of the preemption equipment shall be as approved in advance by Caltrans and shall not be changed without written permission. The Permittee shall make any changes in timing requested by Caltrans.

3. The Permittee shall assume all liability for the claims which arise due to or because of the permit.

Normally emergency vehicle preemption equipment is installed, operated, and maintained at no cost to the State. An exception is where the equipment is installed for use by vehicles of another State agency.

The State will maintain the preemption equipment at the traffic signal when the signal is maintained by the State. The costs of such maintenance shall be at 100% local agency expense.

9-03.31 Bus/Transit Vehicle Priority

The requirements for bus/transit vehicle priority insofar as installation, encroachment permit, maintenance and funding are the same as stated above for emergency vehicle preemption.

The equipment and operation requirements for bus/transit vehicle priority shall be similar to those above for emergency vehicle priority. Some exceptions to these requirements are:

1. Equipment requirements for the transmitter are set forth in Section 25352 of the California Vehicle Code.

2. Any pedestrian interval in effect when priority is initiated shall not have its timing affected.

3. Normally, bus/transit priority should not occur more than once every other signal cycle.

9-03.32 Modification of Existing Signals

Where existing signals are to be modified, it is desirable that the construction plans include a separate plan of the existing system as well as a plan showing the modifications. It may also be necessary to include a tabulation on the plan showing such appurtenances as backplates and special signal faces that may be difficult to discern on a complicated plan.

The design of any signal modification project should include adequate consideration for keeping the existing signals in operation while the modification work is being done.

9-03.33 Signals on Poles Owned by Others

Traffic signal equipment may be attached to poles owned by utility companies or other agencies when it is desired to keep the number of poles at an intersection to a minimum. In such cases, it is necessary to enter into an agreement with the owner of the pole. The agreement should be written to hold the owner of the pole free of liability relative to operation of the traffic signal or damage to the pole and to make the State responsible for moving the equipment in the event the pole is removed or relocated.

9-03.34 Additional Capacity at Signalized Intersections

When the vehicular volume on a two-lane State highway is large enough to warrant traffic signals, usually there will be considerable congestion after the signals are installed unless the State highway is widened to four lanes at the intersection. Sometimes, it is also necessary to widen the intersecting road.

Where possible, the State highway approaches and local road approaches should be widened to two lanes for through traffic, for a minimum of 60 m for traffic approaching the intersection and for a minimum of 100 m for traffic leaving the intersection. Additional widening for tapered sections should be provided at the ends of the added lanes. It may be necessary to prohibit parking in these areas and/or to provide left turn lanes. See Section 9-02.4 for financing.

9-03.35 Temporary Signals for Haul Roads or One-Way Traffic Control in Construction Zones

1. *General.*

   Temporary signals for traffic control at the intersection of a State highway and a haul road, or to provide one-way traffic control through a construction zone, may be either the fixed or portable type. Such signals are normally installed by a contractor and may require an Encroachment Permit.

2. *Requirements.*

   Each plan for temporary signals should include the equipment details as well as the following operating requirements:

   a. Temporary signals shall meet the design standards described earlier in this section.

   b. Signal faces, detectors and control equipment are to be kept in good operating condition at all times.

   c. When not in use, portable signals are to be removed from the vicinity of the highway and fixed signals are to be placed in flashing operation with yellow indications for the highway and red indications for the haul road.

   d. Timing of the signals will be determined by the Agency having jurisdiction.

   e. A SIGNAL AHEAD (W41) sign (and flashing beacon, if required) is to be placed on each approach of the highway in advance of the signal.

   f. Haul road signals shall be operated using manual control or vehicle detectors. The operation shall provide a green indication to the haul road only if the contractor's equipment is approaching the crossing. The haul road green interval shall not exceed 10 seconds and the highway green interval shall not be less than 20 seconds, unless specific permission is given in writing. A 3-second, minimum, yellow change interval, and any required red clearance interval, shall follow each green interval.

   g. One-way traffic control signals may utilize pretimed or traffic-actuated controller units, or may be manually controlled. A 3-second, minimum, yellow change interval shall follow each green interval. An all-red clearance interval shall follow each yellow change interval. The all-red clearance interval shall permit a vehicle to travel the length of the one-way lane before a green indication is shown to opposing traffic.

   h. Failure to comply with any of the above or other specified conditions will be justification for revoking the permit.

3. *Equipment Details.*

   Fixed temporary traffic signals shall be designed for 120-volt operation, while portable temporary signals may be battery operated.

   The vehicle signal faces shall be the standard 3-section type with no less than two separate signal faces for each approach, including the haul road approaches.

The signal faces shall be mounted a minimum of 3 m above the roadway and directed so that the indications are readily seen by traffic. The signal faces for highway traffic shall be equipped with backplates.

For one-way lane control or where conditions require sets of signals to be coordinated, the sets may be interconnected by cable or radio so that they are operated from a single manual or automatic control. The control system shall be designed to prevent conflicting green indications.

9-03.36 Lane-Use Control Signals

Lane-use control signals are special overhead signals having indications used to permit or prohibit the use of specific lanes of a street or highway or to indicate the impending prohibition of use.

Lane-use control signals shall conform to the requirements in Part IV of the MUTCD.

9-03.37 Ramp Metering Signals

Traffic control signals may be installed on freeway entrance ramps to control the flow of traffic entering the freeway facility.

Ramp metering control signals shall conform to the requirements in Part IV of the MUTCD and Caltrans Ramp Meter Design Guidelines.

9-03.38 Signals at Movable Bridges

Signals installed at movable bridges are a special type of highway traffic signal, the purpose of which is to notify traffic to stop because of a road closure rather than alternately giving the right of way to conflicting traffic movements. They are operated in coordination with the opening and closing of the movable bridges. Unlike traffic control signals, movable bridge signals may be operated frequently or at extremely infrequent intervals depending upon waterway traffic. Signals at movable bridges shall conform to the requirements in Part IV of the MUTCD.

Traffic Signal Operations 9-04

9-04.1 Introduction

The California Department of Transportation is responsible for the operation of all State highway traffic signals, regardless of whether the signal is maintained by the State or by others. State highway traffic signals shall include, but are not necessarily limited to, all signals on a State highway and at ramp connections to local streets. Maintenance and operation of highway traffic signals involving State Highways by an agency other than the California Department of Transportation shall require a jointly approved written agreement.

9-04.2 Review of Traffic Signal Operations

All State highway traffic signals should be periodically reviewed for proper operation.

The traffic signal operation should be observed during morning and evening peak traffic periods and during off-peak periods. If an operating deficiency is observed, the reason for the deficiency should be determined. If there is a malfunction, Maintenance should be notified, and after corrective work is done, further surveillance should be conducted to be sure no deficiency remains. If a need for a design change is observed, an analysis should be made to determine what improvement might be necessary to improve the design.

Improvements to consider are:

1. Timing of:
    a. Maximums or Force Offs
    b. Gap Interval
    c. Offsets
    d. Cycle Length
2. Time-of-Day or Traffic Responsive Settings
3. Signal Phasing or Phase Sequence
4. Type of Operation
5. Coordination of Signals
6. Signs, Striping and/or Pavement Markings
7. Roadway Improvements

Initial timing of traffic signals and any subsequent changes in timing shall be the responsibility of Traffic Operations. Timing records shall be kept and be readily available to maintenance and traffic operations staff and other agencies, where appropriate.

Aids for timing are shown in Tables 9-2, 9-3, 9-4, 9-5, 9-6 and 9-7.

9-04.3 Signals at Interchanges

Signals at freeway interchanges require special consideration as to phasing and timing to minimize backup of traffic onto the freeway lanes.

In addition, signals at diamond-type interchanges require phasing and timing to provide the necessary turning movements from the cross street to and from the ramps, without a backup of traffic between the ramps. Tables 9-3 and 9-4 are guides to be used to determine the timing of traffic signals at diamond interchanges. These tables should be used in conjunction with Table 9-2 to determine the timing of the splits and offsets for diamond interchange signals.

The decision whether to use pretimed or traffic-actuated operation is dependent not only upon traffic conditions in the interchange area, but also upon traffic conditions along the cross street. For example, a coordinated traffic signal system along the cross street may require that the signals at the interchange be coordinated with the cross street progression.

9-04.4 Timing of Green Intervals

The proportion of green time, or split, allotted to each phase or combination of phases during a signal cycle, should be as close as practicable to the proportion of critical lane traffic volumes on the respective approaches. In traffic-actuated operation, this proportioning is done automatically and continuously as a result of vehicle detector inputs to the controller unit.

Factors that may modify this proportioning are the time required for pedestrian intervals and the requirements of a coordinated system.

In the usual signal operation, predetermined splits can be selected by time-of-day or traffic-responsive equipment. In coordinated signal systems, the cycle length and the split can be varied by command from the system master controller.

9-04.5 Yellow Change Intervals

The purpose of the yellow signal indication is to warn traffic approaching the signal that the related green movement is ending or that a red indication will be exhibited immediately thereafter and traffic will be required to stop when the red signal is exhibited.

The length of the yellow change interval is dependent upon the speed of approaching traffic. Suggested yellow intervals are shown below are calculated by using the formula as shown in Table 9-1:

Approach Speed mph (km/h)	Yellow Interval (seconds)
25 or less (40 or less)	3.0
30 (48)	3.2
35 (56)	3.6
40 (64)	3.9
45 (72)	4.3
50 (80)	4.7
55 (89)	5.0
60 (97)	5.4
65 (105)	5.8

9-04.6 Red Clearance Intervals

Red clearance intervals which follow yellow change intervals are not required, but may be considered where any of the following conditions exist: intersections that are wide, offset or contain unusual geometry; intersections where the visibility of conflicting traffic is blocked or limited; movements where the approach speeds are 88 km/hr (55 mph) or more; or where it is desirable to help clear vehicles that recurrently become queued in the intersection where there are permissive left turns. Normally, red clearance intervals range from 0.01 to 2.0 seconds and should not exceed 6 seconds.

9-04.7 Operation of Pedestrian Indications

Pedestrian signal faces shall be operated so as to display three indications: Steady WALKING PERSON or "WALK", flashing upraised HAND or "DONT WALK", and steady upraised HAND or "DONT WALK". The flashing indication is displayed following the walk interval.

The total pedestrian crossing time shall consist of the walk interval plus the pedestrian clearance time obtained by using a walking rate of 1.2 m/s. Under normal conditions, the walk interval should be at least four seconds in length. On an undivided highway, the pedestrian clearance time should be no less than the time required to walk from the curb to the center of the farthest traveled lane before opposing vehicles receive a green indication.

On a street with a median sufficient for a pedestrian to wait, the pedestrian clearance time should be no less than the time required to walk from the curb to the median before opposing vehicles receive a green indication.

Pedestrian signal indications should normally be operated in conjunction with a vehicle phase. Pedestrian signals shall be turned off during flashing operation of vehicle signal faces.

9-04.8 Audible Pedestrian Signals

1. *General.*

Audible Pedestrian Signals may be installed at signalized intersection crosswalks. These devices supplement visual WALK indications and are designed to aid visually impaired pedestrians. The installation of Audible Pedestrian Signals may be considered when an engineering study and evaluation have been conducted and the following minimum conditions have been met:

a. The proposed intersection crosswalk must be signalized.

b. The audible devices should be retrofittable to the existing traffic signal hardware.

c. The signalized intersection should be equipped with pedestrian push buttons.

d. The selected crosswalk must be suitable for the installation of audible signals, in terms of surrounding land use and traffic patterns.

e. There must be a demonstrated need for the audible signals in the form of a request from an individual or group that would use the audible signal.

f. The individual or group requesting the device should agree to train the visually impaired users of the audible signals.

It is recommended that the audible devices selected emit a "Cuckoo" walk sound for a crosswalk in the North-South direction and a "Peep-Peep" walk sound for a crosswalk in the East-West direction.

2. *Financing.*

The cost of installing Audible Pedestrian Signals shall be shared with the local agency in the same manner as a traffic signal. See Section 9-02.4.

9-04.9 Continuity of Operation

Once a traffic signal at an intersection or pedestrian crossing has been energized, it shall not be turned off unless arrangements have been made for temporary control by traffic officers, temporary stop signs or an approved portable signal.

When a traffic signal at an intersection or pedestrian crossing is not to be in operation for a planned, extended period of time, the signal faces should be hooded, turned away from traffic or removed.

Refer to the Highway Maintenance Manual for procedures to provide traffic controls at signalized intersections during planned or unplanned utility company power outages.

9-04.10 Flashing Operation

Flashing operation may be used prior to placing the signal in automatic stop-and-go operation or when required by seasonal traffic conditions. During flashing operation, red/yellow or all red indications may be used.

Pretimed or semi-traffic-actuated traffic signals may be operated in a flashing mode at night. Flashing yellow operation for the major street in a coordinated signal system reduces control of vehicle speed. If such speed control is desired, properly spaced signals should remain in automatic stop-and-go operation.

Actuated signals at an isolated intersection should never be operated in a flashing mode except during emergencies, the operation of a conflict monitoring device, or during railroad preemption.

The emergency mode of operation for all traffic signals shall be flashing operation.

Table 9-1
SUGGESTED DETECTOR SETBACKS FROM LIMITLINE

Deceleration Rate d = 3.05 m per second^2

Deceleration Time = $\frac{V}{d}$

Deceleration Distance = $\frac{1}{2}dt^2$ or $\frac{1}{2}Vt$ or $\frac{V^2}{2d}$

Reaction Time r = 1.00 second

Reaction Distance = Vr

Total Time = Deceleration Time + Reaction Time = t + r or $\frac{V}{d} + r$

Detector Setback = Deceleration Distance + Reaction Distance = $\frac{V^2}{2d} + Vr$

Yellow Interval T = r + $\frac{V}{2d}$

V = Speed (meter per second)

d = Deceleration Rate (meter per second^2)

t = Deceleration Time (seconds)

T = Yellow Interval (seconds)

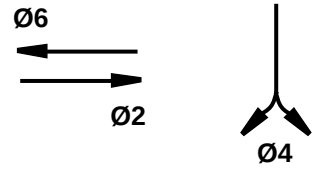
SPEED			DEC. TIME	DEC. DIST.	TOTAL TIME	DETECTOR SETBACKS	
						ACTUAL	SUGGESTED
mph	km/h	m/s	Seconds	Meters	Seconds	Meters	Meters
25	40	11.18	3.67	20.49	4.67	31.67	30
30	48	13.42	4.40	29.51	5.40	42.93	45
35	56	15.65	5.13	40.17	6.13	55.82	55
40	64	17.89	5.87	52.46	6.87	70.35	70
45	72	20.13	6.60	66.40	7.60	86.52	85
50	80	22.36	7.33	81.97	8.33	104.33	105
55	89	24.60	8.06	99.18	9.06	123.78	125
60	97	26.83	8.80	118.04	9.80	144.87	145
65	105	29.07	9.53	138.53	10.53	167.60	170
70	113	31.29	10.27	160.50	11.27	191.79	190

Table 9-2
TRAFFIC SIGNAL TIMING ANALYSIS CHART

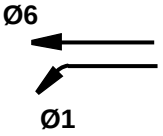
No. of Cars	Min. Time in Second Reg. for Cars	Length (m) in Stopped Queue	Length (m) of Moving Queue 48 km/h	Moving Queue Time (Band Width in Seconds)	NUMBER OF VEHICLES PER HOUR LANE AT INDICATED CYCLE LENGTH									
					50 Sec.	**60 Sec.**	**70 Sec.**	**80 Sec.**	**90 Sec.**	**100 Sec.**	**120 Sec.**	**150 Sec.**	**180 Sec.**	**240 Sec.**
1	4	8	0	2	70	60	50	45	40	35	30	25	20	15
2	7	16	27	4	145	120	100	90	80	70	60	50	40	30
3	9	24	54	6	215	180	150	135	120	110	90	70	60	45
4	11	32	81	8	290	240	205	180	160	145	120	95	80	60
5	13	40	108	10	360	300	255	225	200	180	150	120	100	75
6	15	48	135	12	430	360	310	270	240	215	180	145	120	90
7	17	54	162	14	505	420	360	315	280	250	210	170	140	105
8	19	62	189	16	575	480	410	360	320	290	240	190	160	120
9	21	70	216	18	650	540	460	405	360	320	270	215	180	135
10	23	78	243	20	720	600	510	450	400	360	300	240	200	150
11	25	84	270	22	790	660	560	495	440	400	330	265	220	165
12	27	92	297	24	865	720	610	540	480	430	360	290	240	180
13	29	100	324	26	935	780	665	585	520	470	390	315	260	195
14	31	108	351	28	1020	840	715	630	560	500	420	340	280	210
15	33	114	378	30	1080	900	765	675	600	540	450	365	300	225
16	35	122	405	32	1150	960	815	720	640	580	480	385	320	240
17	37	130	432	34	1225	1020	865	765	680	610	510	410	340	255
18	39	138	459	36	1295	1080	920	810	720	650	540	430	360	270
19	41	146	486	38		1140	970	855	760	680	570	455	380	285
20	43	154	513	40		1200	1020	900	800	720	600	480	400	300
21	45	162	540	42		1260	1070	945	840	760	630	505	420	315
22	47	170	567	44		1320	1120	990	880	790	660	530	440	330
23	49	178	594	46		1380	1175	1035	920	830	690	550	460	345
24	51	186	621	48		1440	1225	1080	960	860	720	575	480	360
25	53	194	648	50			1275	1125	1000	900	750	600	500	375
26	55	202	675	52			1325	1170	1040	930	780	625	520	390
27	57	210	702	54			1375	1215	1080	960	810	650	540	405
28	59	218	724	56			1430	1260	1120	990	840	670	500	420
29	61	226	756	58				1305	1160	1020	870	700	580	435

Table 9-3
DIAMOND INTERCHANGE TIMING CHART
(Heavy Left-Turn - 200 vphpl or more - Using Two Controllers)

Phase Diagram

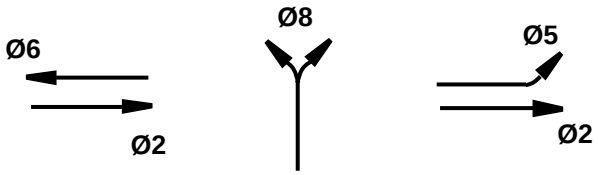


Ø2 and Ø6 Ø4



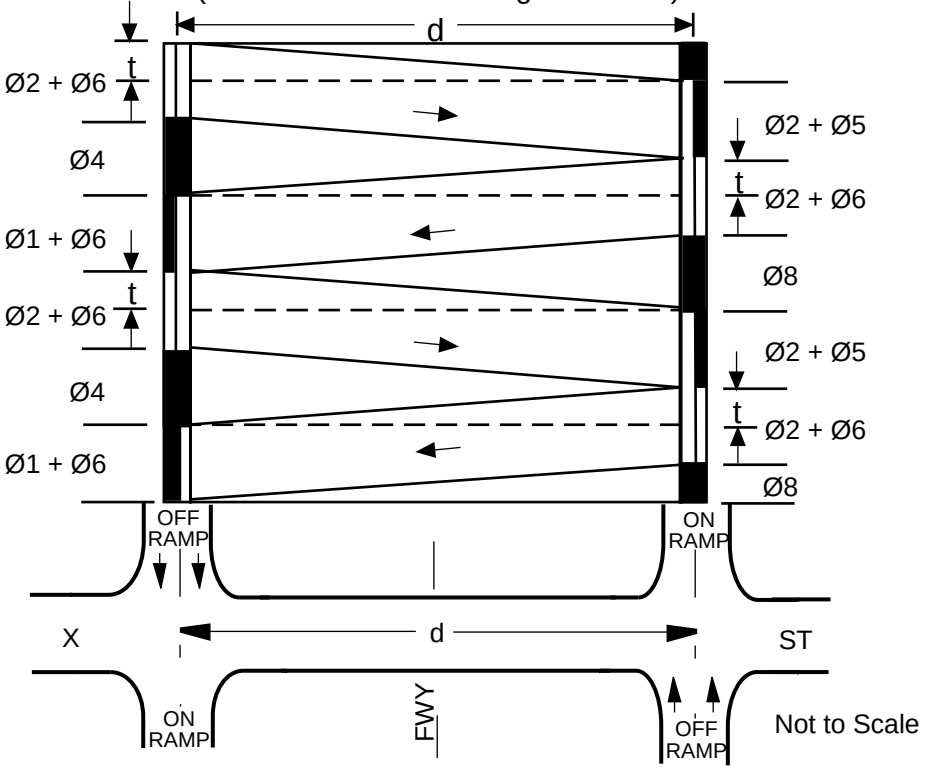
Ø1 and Ø6

Phase Diagram

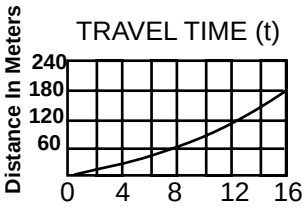


Ø2 and Ø6 Ø8 Ø2 and Ø5

(Use when left turn storage is limited)



Ø2 + Ø6 should be = <Ø5
Ø2 + Ø6 should be = <Ø1
Ø4 should be = <Ø2 + Ø6
Ø8 should be = <Ø2 + Ø6
Phase times are green-yellow

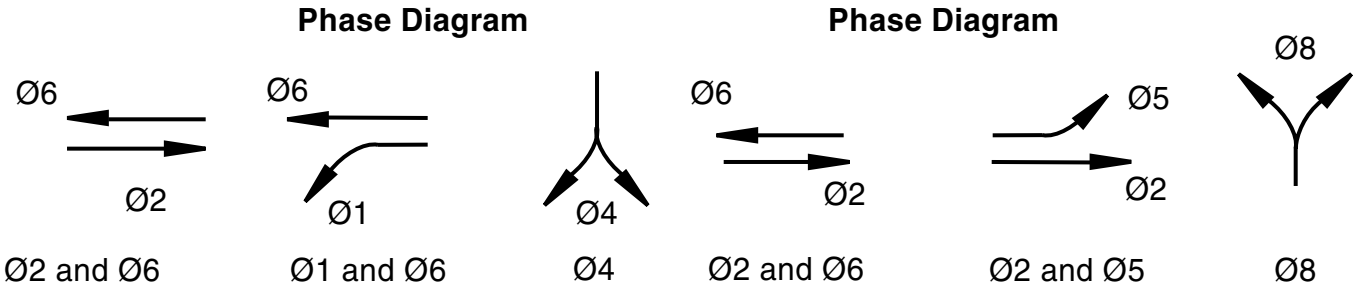


Average: 56 km/h Acceleration Time

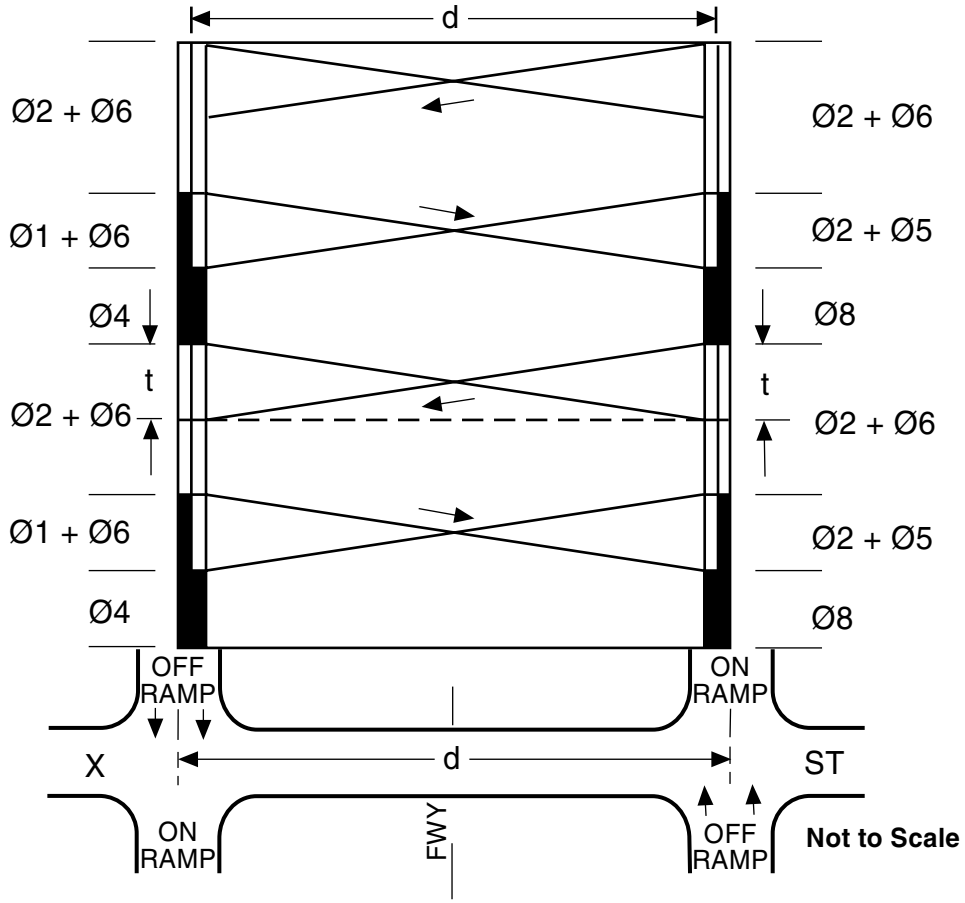
2t + Ø1 + Ø5 = Cycle length
Ø2 + Ø6 + Ø4 = 2t + Ø5
Ø2 + Ø6 + Ø8 = 2t + Ø1
"t" = Time to go distance "d"

NOTE: These timing guidelines are ideal. Variations in timing may be necessary to provide proper splits to meet volume demands (See Table 9-1).

Table 9-4
DIAMOND INTERCHANGE TIMING CHART
(Light Left-Turn - 200 vphpl or less - Using Two Controllers)



(Use when left turn storage is limited)



"t" = time to go distance "d"

NOTE:
1. These timing guidelines are ideal. Variations in timing may be necessary to provide proper splits to meet volume demands (See Table 9-1).
2. The green-yellow interval for phases 1,4,5 or 8 should equal time "t".

Table 9-5
TRAFFIC SIGNAL OPERATIONS
(Vehicular Speed Table)

SECONDS		10	15	20	25	30	35	40	45	50	55	60
km/h	m/s	Distance Traveled in Meters										
1	0.28	2.8	4.2	5.6	7	8.4	9.8	11.2	12.6	14	15.4	16.8
2	0.56	5.6	8.4	11.2	14	16.8	19.6	22.4	25.2	28	30.8	33.6
3	0.83	8.3	12.45	16.6	20.75	24.9	29.05	33.2	37.35	41.5	45.65	49.8
4	1.10	1.1	16.5	22	27.5	33	38.5	44	49.5	55	60.5	66
5	1.39	13.9	20.85	27.8	34.75	41.7	48.65	55.6	62.55	69.5	76.45	83.4
10	2.80	2.8	42	56	70	84	98	112	126	140	154	168
15	4.17	41.7	62.6	83.4	104.3	125	146	167	188	209	229	250
20	5.56	55.6	84	111	139	167	195	222	250	278	306	334
25	6.94	69.4	104	139	174	208	243	278	312	347	382	416
30	8.33	83.3	125	167	208	250	292	333	375	417	458	500
35	9.72	97.2	146	194	243	292	340	389	437	486	535	583
40	11.10	111	167	222	278	333	389	444	500	555	611	666
45	12.50	125	188	250	313	375	438	500	563	625	688	750
50	13.89	138.9	208	278	347	417	486	556	625	695	764	834
55	15.28	152.8	229	306	382	458	535	611	688	764	840	917
60	16.67	166.7	250	333	416	500	583	667	750	833	917	1000
65	18.06	180.6	271	361	452	542	632	722	813	903	993	1084
70	19.44	194.4	292	389	486	583	680	778	875	972	1069	1166
75	20.83	208.3	312	417	521	625	729	833	937	1042	1146	1250
80	22.22	222.2	333	444	555	667	778	889	1000	1111	1222	1333
85	23.61	236.1	354	472	590	708	826	944	1062	1180	1298	1416
90	25.00	250	375	500	625	750	875	1000	1125	1250	1375	1500
95	26.39	263.9	396	528	660	792	924	1056	1188	1320	1452	1584
100	27.78	277.8	417	556	695	834	972	1112	1251	1390	1529	1668
105	29.17	291.7	437	583	729	875	1021	1167	1313	1458	1604	1750
110	30.56	305.6	458	611	764	917	1070	1222	1375	1528	1681	1834

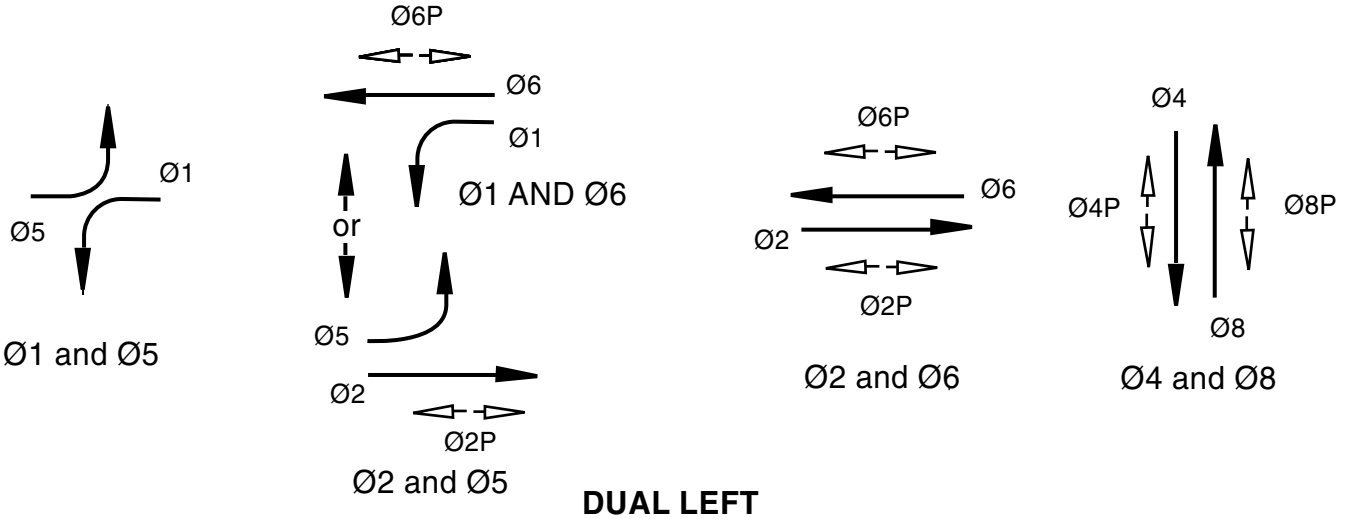
Table 9-6
TRAFFIC SIGNAL OPERATIONS
(Cycle Percentage Conversion Table)

PERCENT	50	60	70	80	90	100	110	120	150	180	240
1	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.5	1.8	2.4
2	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	3.0	3.6	4.8
3	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6	4.5	5.4	7.2
4	2.0	2.4	2.8	3.2	3.6	4.0	4.4	4.8	6.0	7.2	9.6
5	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.5	9.0	12.0
6	3.0	3.6	4.2	4.8	5.4	6.0	6.6	7.2	9.0	10.8	14.4
7	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	10.5	12.6	16.8
8	4.0	4.8	5.6	6.4	7.2	8.0	8.8	9.6	12.0	14.4	19.2
9	4.5	5.4	6.3	7.2	8.1	9.0	9.9	10.8	13.5	16.2	21.6
10	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	15.0	18.0	24.0
11	5.5	6.6	7.7	8.8	9.9	11.0	12.1	13.2	16.5	19.8	26.4
12	6.0	7.2	8.4	9.6	10.8	12.0	13.2	14.4	18.0	21.6	28.8
13	6.5	7.8	9.1	10.4	11.7	13.0	14.3	15.6	19.5	23.4	31.2
14	7.0	8.4	9.8	11.2	12.6	14.0	15.4	16.8	21.0	25.2	33.6
15	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	22.5	27.0	36.0
16	8.0	9.6	11.2	12.8	14.4	16.0	17.6	19.2	24.0	28.8	38.4
17	8.5	10.2	11.9	13.6	15.3	17.0	18.7	20.4	25.5	30.6	40.8
18	9.0	10.8	12.6	14.4	16.2	18.0	19.8	21.6	27.0	32.4	43.2
19	9.5	11.4	13.3	15.2	17.1	19.0	20.9	22.8	28.5	34.2	45.6
20	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	30.0	36.0	48.0
21	10.5	12.6	14.7	16.8	18.9	21.0	23.1	25.2	31.5	37.8	50.4
22	11.0	13.2	15.4	17.6	19.8	22.0	24.2	26.4	33.0	39.6	52.8
23	11.5	13.8	16.1	18.4	20.7	23.0	25.3	27.6	34.5	41.4	55.2
24	12.0	14.4	16.8	19.2	21.6	24.0	26.4	28.8	36.0	43.2	57.6
25	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0	37.5	45.0	60.0
26	13.0	15.6	18.2	20.8	23.4	26.0	28.6	31.2	39.0	46.8	62.4
27	13.5	16.2	18.9	21.6	24.3	27.0	29.7	32.4	40.5	48.6	64.8
28	14.0	16.8	19.6	22.4	25.2	28.0	30.8	33.6	42.0	50.4	67.2
29	14.5	17.4	20.3	23.2	26.1	29.0	31.9	34.8	43.5	52.2	69.6
30	15.0	18.0	21.0	24.0	27.0	30.0	33.0	36.0	45.0	54.0	72.0
31	15.5	18.6	21.7	24.8	27.9	31.0	34.1	37.2	46.5	55.8	74.4
32	16.0	19.2	22.4	25.6	28.8	32.0	35.2	38.4	48.0	57.6	76.8
33	16.5	19.8	23.1	26.4	29.7	33.0	36.3	39.6	49.5	59.4	79.2
34	17.0	20.4	23.8	27.2	30.6	34.0	37.4	40.8	51.0	61.2	81.6
35	17.5	21.0	24.5	28.0	31.5	35.0	38.5	42.0	52.5	63.0	84.0
36	18.0	21.6	25.2	28.8	32.4	36.0	39.6	43.2	54.0	64.8	86.4
37	18.5	22.2	25.9	29.6	33.3	37.0	40.7	44.4	55.5	66.6	88.8
38	19.0	22.8	26.6	30.4	34.2	38.0	41.8	45.6	57.0	68.4	91.2
39	19.5	23.4	27.3	31.2	35.1	39.0	42.9	46.8	58.5	70.2	93.6
40	20.0	24.0	28.0	32.0	36.0	40.0	44.0	48.0	60.0	72.0	96.0
41	20.5	24.6	28.7	32.8	36.9	41.0	45.1	49.2	61.5	73.8	98.4
42	21.0	25.2	29.4	33.6	37.8	42.0	46.2	50.4	63.0	75.6	100.8
43	21.5	25.8	30.1	34.4	38.7	43.0	47.3	51.6	64.5	77.4	103.2
44	22.0	26.4	30.8	35.2	39.6	44.0	48.4	52.8	66.0	79.2	105.6
45	22.5	27.0	31.5	36.0	40.5	45.0	49.5	54.0	67.5	81.0	108.0
46	23.0	27.6	32.2	36.8	41.4	46.0	50.6	55.2	69.0	82.8	110.4
47	23.5	28.2	32.9	37.6	42.3	47.0	51.7	56.4	70.5	84.6	112.8
48	24.0	28.8	33.6	38.4	43.2	48.0	52.8	57.6	72.0	86.4	115.2
49	24.5	29.4	34.3	39.2	44.1	49.0	53.9	58.8	73.5	88.2	117.6
50	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	75.0	90.0	120.0

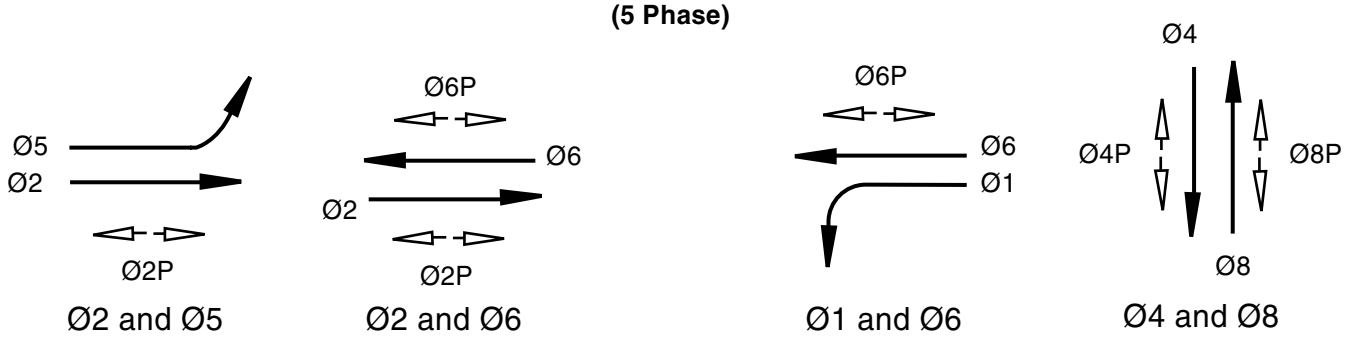
Table 9-7
TRAFFIC SIGNAL OPERATIONS
(Cycle Percentage Conversion Table)

PERCENT	50	60	70	80	90	100	110	120	150	180	240
51	25.5	30.6	35.7	40.8	45.9	51.0	56.1	61.2	76.5	91.8	122.4
52	26.0	31.2	36.4	41.6	46.8	52.0	57.2	62.4	78.0	93.6	124.8
53	26.5	31.8	37.1	42.4	47.7	53.0	58.3	63.6	79.5	95.4	127.2
54	27.0	32.4	37.8	43.2	48.6	54.0	59.4	64.8	81.0	97.2	129.6
55	27.5	33.0	38.5	44.0	49.5	55.0	60.5	66.0	82.5	99.0	132.0
56	28.0	33.6	39.2	44.8	50.4	56.0	61.6	67.2	84.0	100.8	134.4
57	28.5	34.2	39.9	45.6	51.3	57.0	62.7	68.4	85.5	102.6	136.8
58	29.0	34.8	40.6	46.4	52.2	58.0	63.8	69.6	87.0	104.4	139.2
59	29.5	35.4	41.3	47.2	53.1	59.0	64.9	70.8	88.5	106.2	141.6
60	30.0	36.0	42.0	48.0	54.0	60.0	66.0	72.0	90.0	108.0	144.0
61	30.5	36.6	42.7	48.8	54.9	61.0	67.1	73.2	91.5	109.8	146.4
62	31.0	37.2	43.4	49.6	55.8	62.0	68.2	74.4	93.0	111.6	148.8
63	31.5	37.8	44.1	50.4	56.7	63.0	69.3	75.6	94.5	113.4	151.2
64	32.0	38.4	44.8	51.2	57.6	64.0	70.4	76.8	96.0	115.2	153.6
65	32.5	39.0	45.5	52.0	58.5	65.0	71.5	78.0	97.5	117.0	156.0
66	33.0	39.6	46.2	52.8	59.4	66.0	72.6	79.2	99.0	118.8	158.4
67	33.5	40.2	46.9	53.6	60.3	67.0	73.7	80.4	100.5	120.6	160.8
68	34.0	40.8	47.6	54.4	61.2	68.0	74.8	81.6	102.0	122.4	163.2
69	34.5	41.4	48.3	55.2	62.1	69.0	75.9	82.8	103.5	124.2	165.6
70	35.0	42.0	49.0	56.0	63.0	70.0	77.0	84.0	105.0	126.0	168.0
71	35.5	42.6	49.7	56.8	63.9	71.0	78.1	85.2	106.5	127.8	170.4
72	36.0	43.2	50.4	57.6	64.8	72.0	79.2	86.4	108.0	129.6	172.8
73	36.5	43.8	51.1	58.4	65.7	73.0	80.3	87.6	109.5	131.4	175.2
74	37.0	44.4	51.8	59.2	66.6	74.0	81.4	88.8	111.0	133.2	177.6
75	37.5	45.0	52.5	60.0	67.5	75.0	82.5	90.0	112.5	135.0	180.0
76	38.0	45.6	53.2	60.8	68.4	76.0	83.6	91.2	114.0	136.8	182.4
77	38.5	46.2	53.9	61.6	69.3	77.0	84.7	92.4	115.5	138.6	184.8
78	39.0	46.8	54.6	62.4	70.2	78.0	85.8	93.6	117.0	140.4	187.2
79	39.5	47.4	55.3	63.2	71.1	79.0	86.9	94.8	118.5	142.2	189.6
80	40.0	48.0	56.0	64.0	72.0	80.0	88.0	96.0	120.0	144.0	192.0
81	40.5	48.6	56.7	64.8	72.9	81.0	89.1	97.2	121.5	145.8	194.4
82	41.0	49.2	57.4	65.6	73.8	82.0	90.2	98.4	123.0	147.6	196.8
83	41.5	49.8	58.1	66.4	74.7	83.0	91.3	99.6	124.5	149.4	199.2
84	42.0	50.4	58.8	67.2	75.6	84.0	92.4	100.8	126.0	151.2	201.6
85	42.5	51.0	59.5	68.0	76.5	85.0	93.5	102.0	127.5	153.0	204.0
86	43.0	51.6	60.2	68.8	77.4	86.0	94.6	103.2	129.0	154.8	206.4
87	43.5	52.2	60.9	69.6	78.3	87.0	95.7	104.4	130.5	156.6	208.8
88	44.0	52.8	61.6	70.4	79.2	88.0	96.8	105.6	132.0	158.4	211.2
89	44.5	53.4	62.3	71.2	80.1	89.0	97.9	106.8	133.5	160.2	213.6
90	45.0	54.0	63.0	72.0	81.0	90.0	99.0	108.0	135.0	162.0	216.0
91	45.5	54.6	63.7	72.8	81.9	91.0	100.1	109.2	136.5	163.8	218.4
92	46.0	55.2	64.4	73.6	82.8	92.0	101.2	110.4	138.0	165.6	220.8
93	46.5	55.8	65.1	74.4	83.7	93.0	102.3	111.6	139.5	167.4	223.2
94	47.0	56.4	65.8	75.2	84.6	94.0	103.4	112.8	141.0	169.2	225.6
95	47.5	57.0	66.5	76.0	85.5	95.0	104.5	114.0	142.5	171.0	228.0
96	48.0	57.6	67.2	76.8	86.4	96.0	105.6	115.2	144.0	172.8	230.4
97	48.5	58.2	67.9	77.6	87.3	97.0	106.7	116.4	145.5	174.6	232.8
98	49.0	58.8	68.6	78.4	88.2	98.0	107.8	117.6	147.0	176.4	235.2
99	49.5	59.4	69.3	79.2	89.1	99.0	108.9	118.8	148.5	178.2	237.6

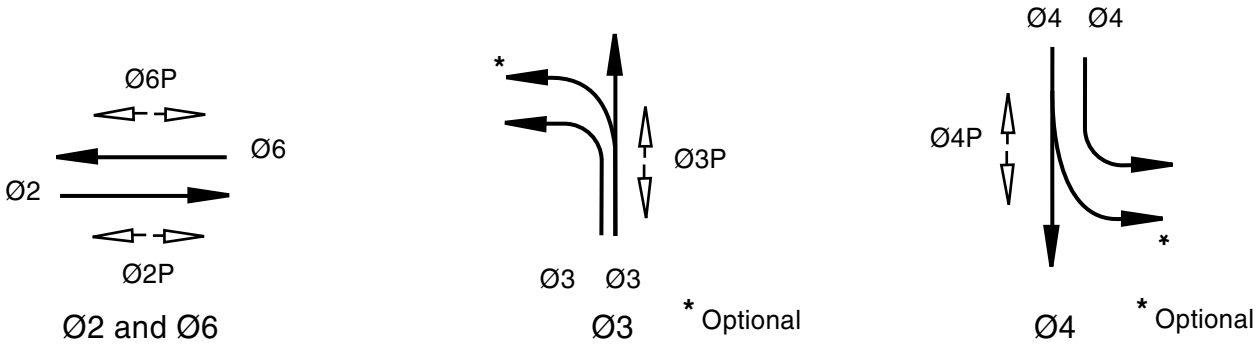
Figure 9-11
LEFT-TURN PHASING METHODS
(Phase Diagrams)



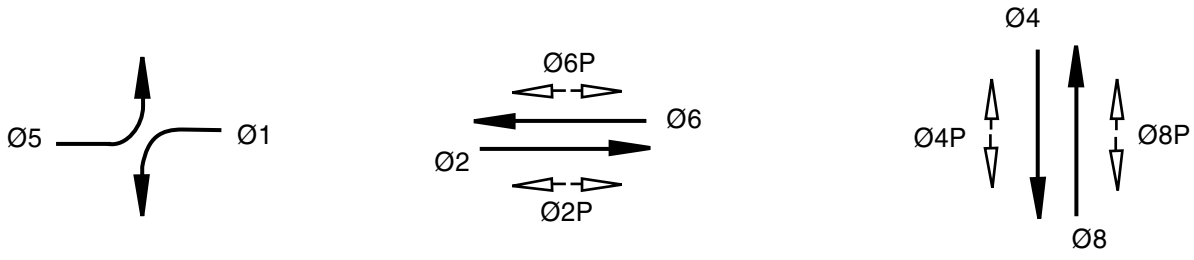
DUAL LEFT
(5 Phase)



LEAD - LAG

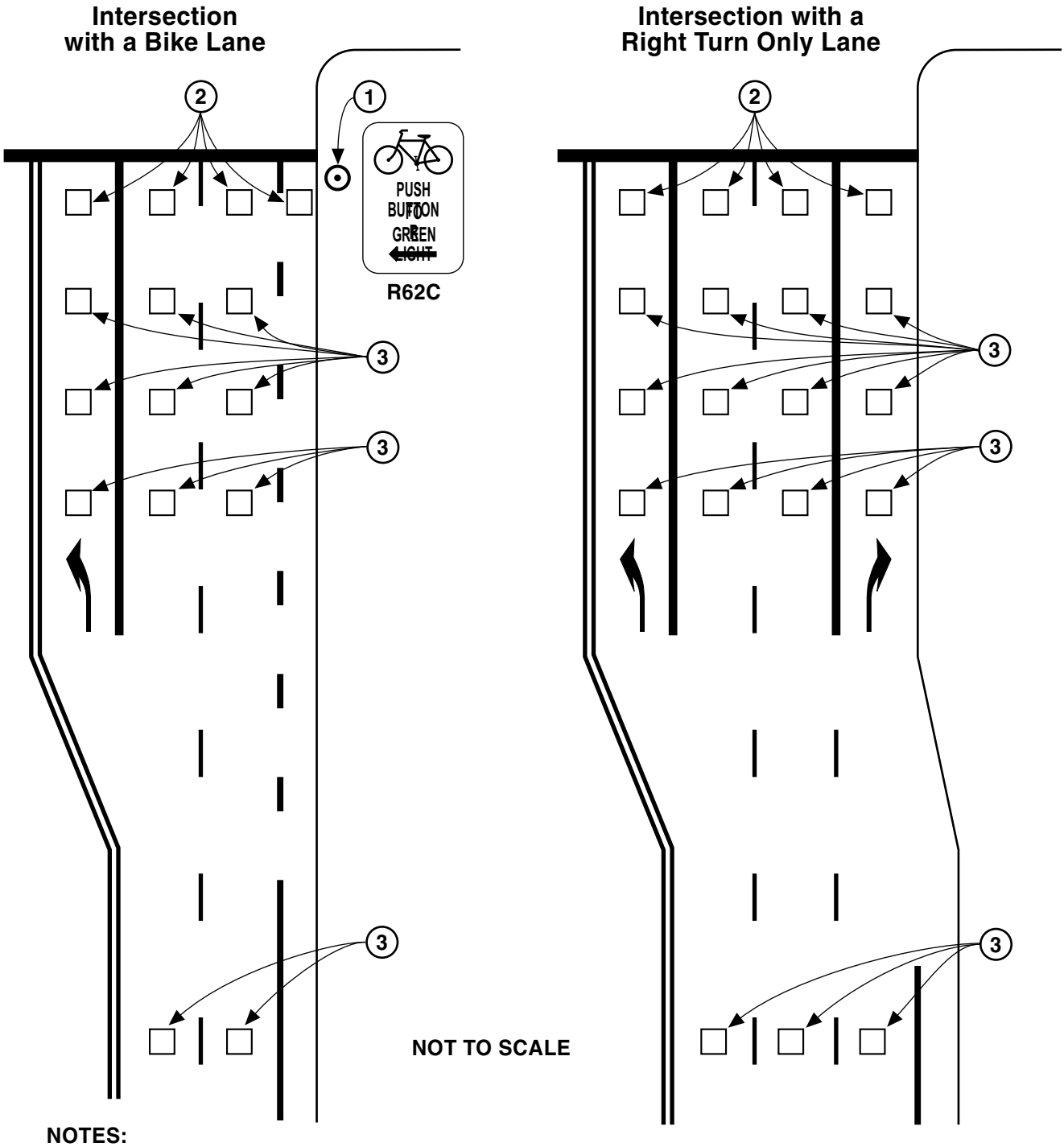


OPPOSITE (OPPOSING)



THREE PHASE

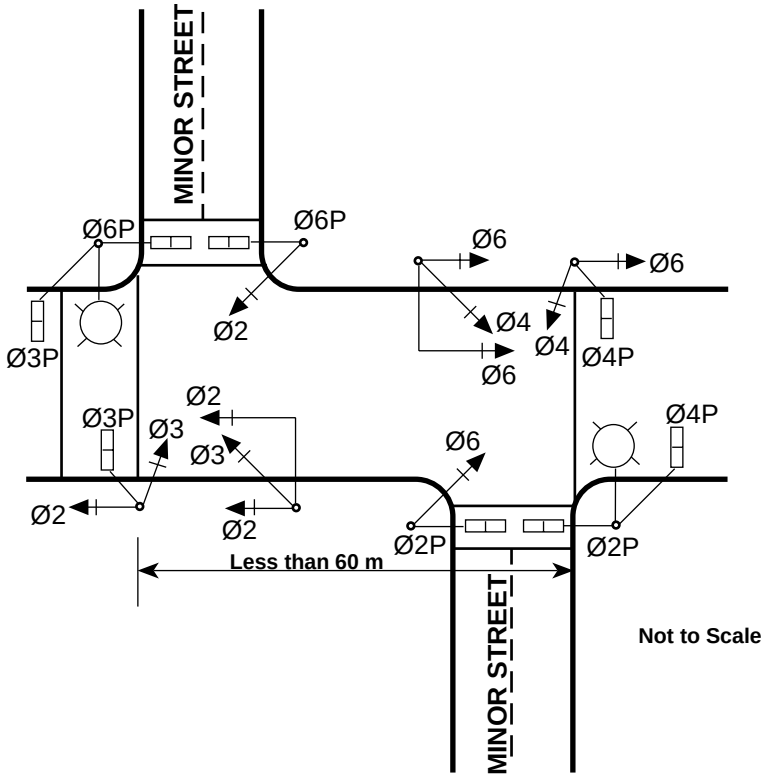
Figure 9-12
BICYCLE DETECTION SYSTEMS



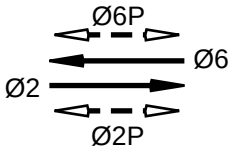
NOTES:

1. **Bicycle Push Button and Sign (R62C) or a Type D Loop Detector may be used to activate a traffic signal. A push button should be located so it is convenient to use by bicyclists.**
2. **Typical Type D Loop Detector locations.**
3. **Typical Loop Detector locations. See Section 9-03.24.**
4. **See Standard Plan A24C for Bicycle Loop Detector pavement marking details.**

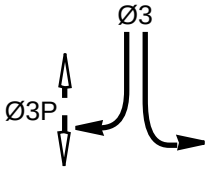
Figure 9-13
TYPICAL SIGNAL LAYOUT AT OFFSET INTERSECTIONS
(Signalized and Marked as a Single Intersection)



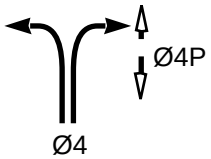
Phase Diagram



Ø2 and Ø6



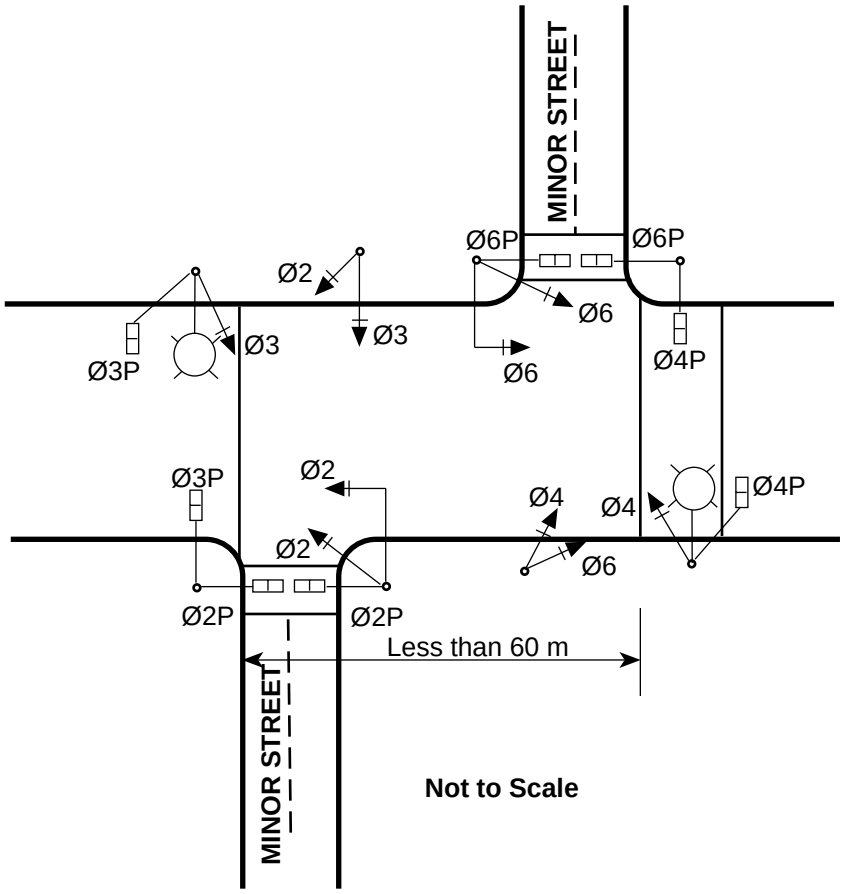
Ø3



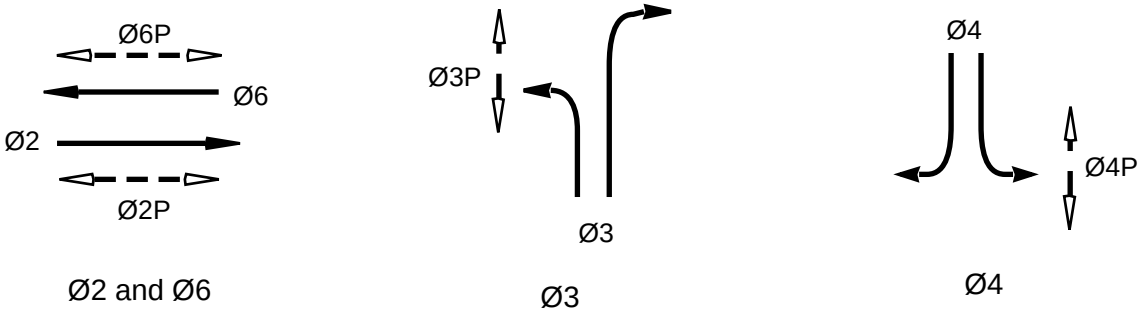
Ø4

NOTE: Safety Lighting Design shall satisfy the requirements of Section 9-10.3.

Figure 9-14
TYPICAL SIGNAL LAYOUT AT OFFSET INTERSECTIONS
(Signalized and Marked as a Single Intersection)



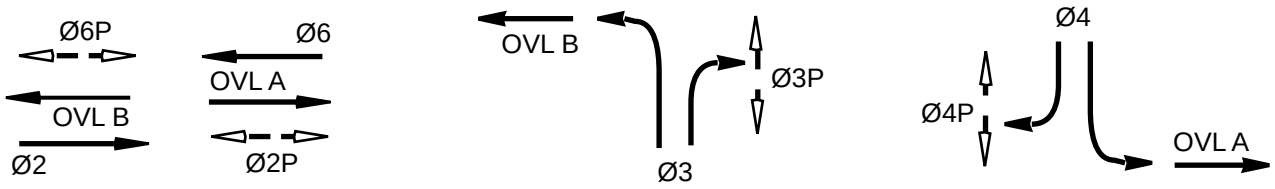
Phase Diagram



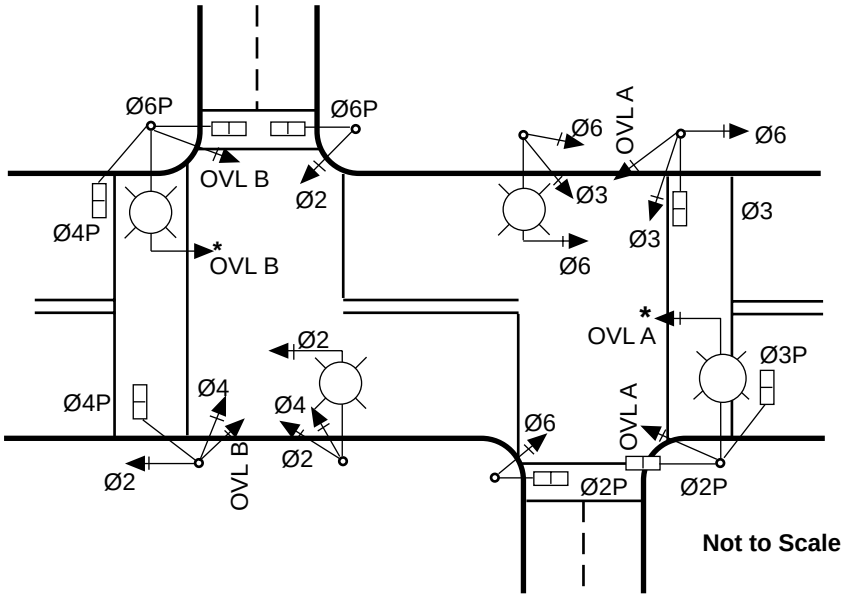
NOTE: Safety Lighting Design shall satisfy the requirements of Section 9-10.3.

Figure 9-15
TYPICAL SIGNAL LAYOUT AT OFFSET INTERSECTIONS
(Signalized and Marked as a Single Intersection)

Phase Diagram



Ø2 and Ø6 Ø3 Ø4

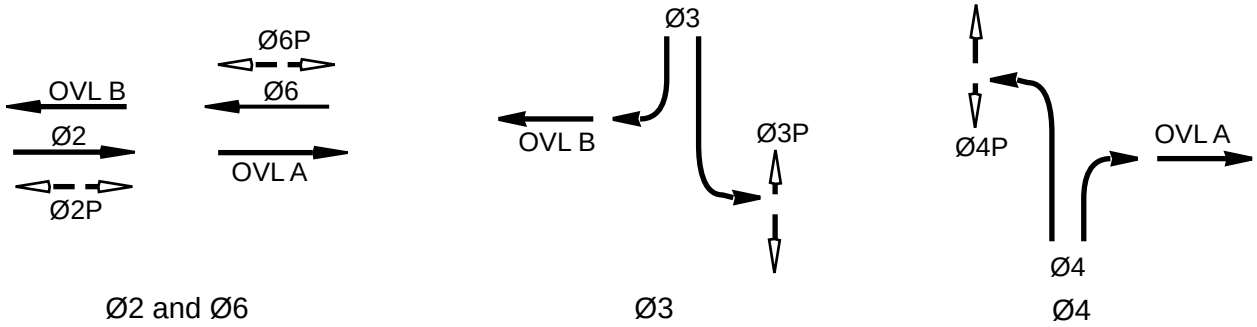


*** Programmed Visibility Indications, if required.**

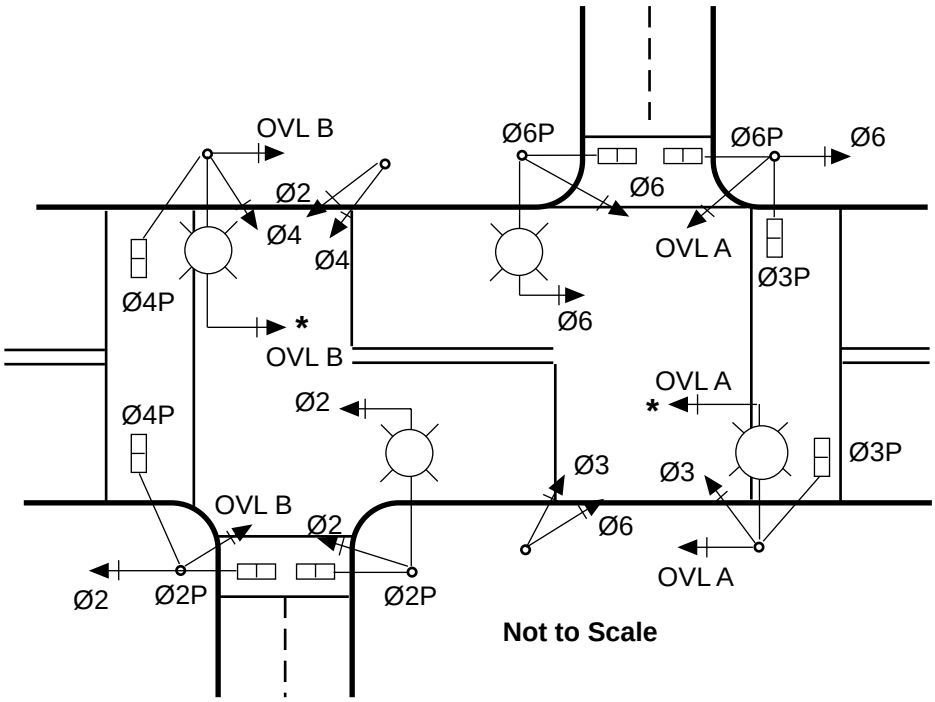
NOTE: Safety Lighting Design shall satisfy the requirements of Section 9-10.3.

Figure 9-16
TYPICAL SIGNAL LAYOUT AT OFFSET INTERSECTIONS
(Signalized and Marked as a Single Intersection)

Phase Diagram



Ø2 and Ø6 Ø3 Ø4



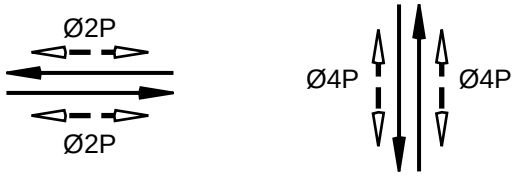
Not to Scale

*** Programmed Visibility Indications, if required.**

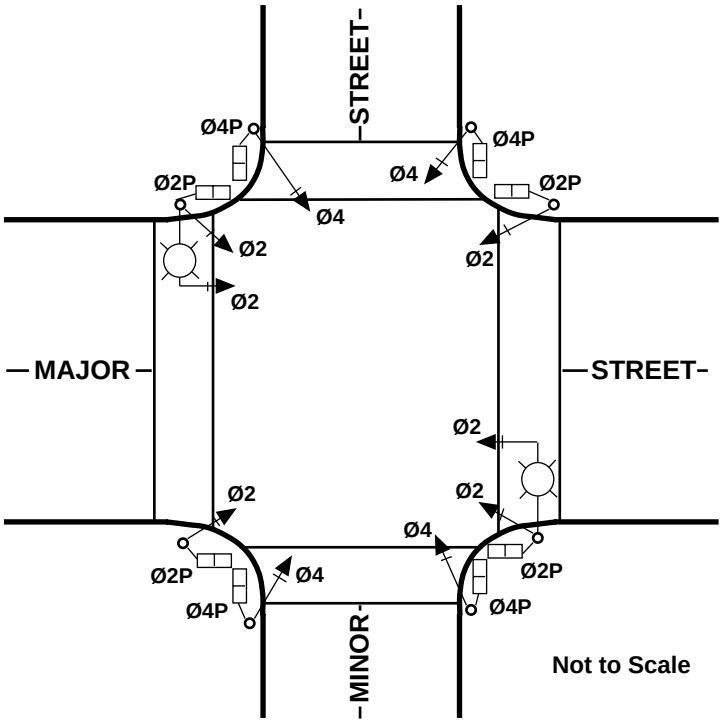
NOTE: Safety Lighting Design shall satisfy the requirements of Section 9-10.3.

Figure 9-17
TYPICAL SIGNAL LAYOUT
(Two Phase Operation)

Phase Diagram



Ø2 Ø4

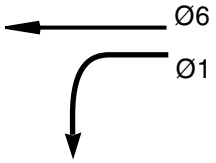


LEGEND:

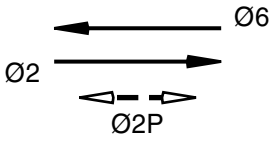
Signal face with backplate
Pedestrian signal face
Standard with luminaire and signal mast arm

Figure 9-18
TYPICAL SIGNAL LAYOUT
(Three Phase Operation)

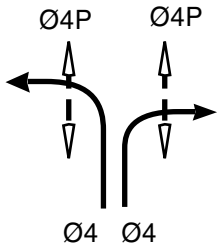
Phase Diagram



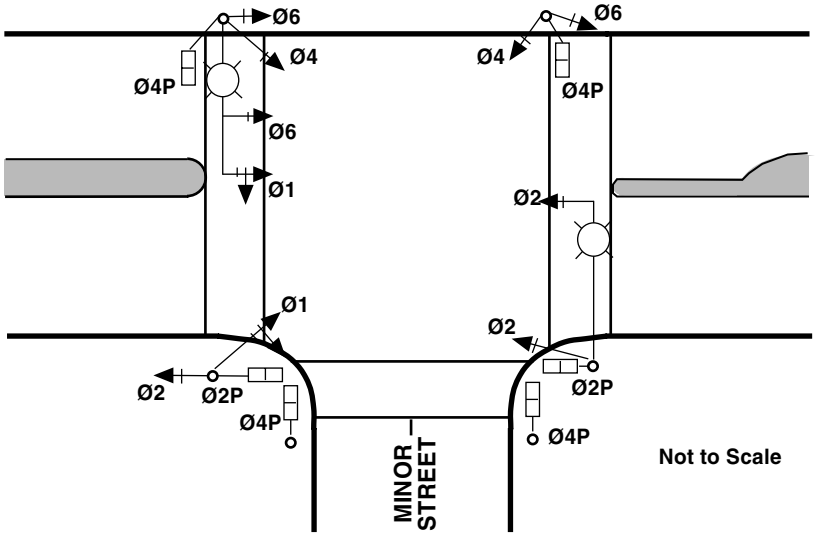
Ø1 and Ø6



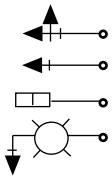
Ø2 and Ø6



Ø4



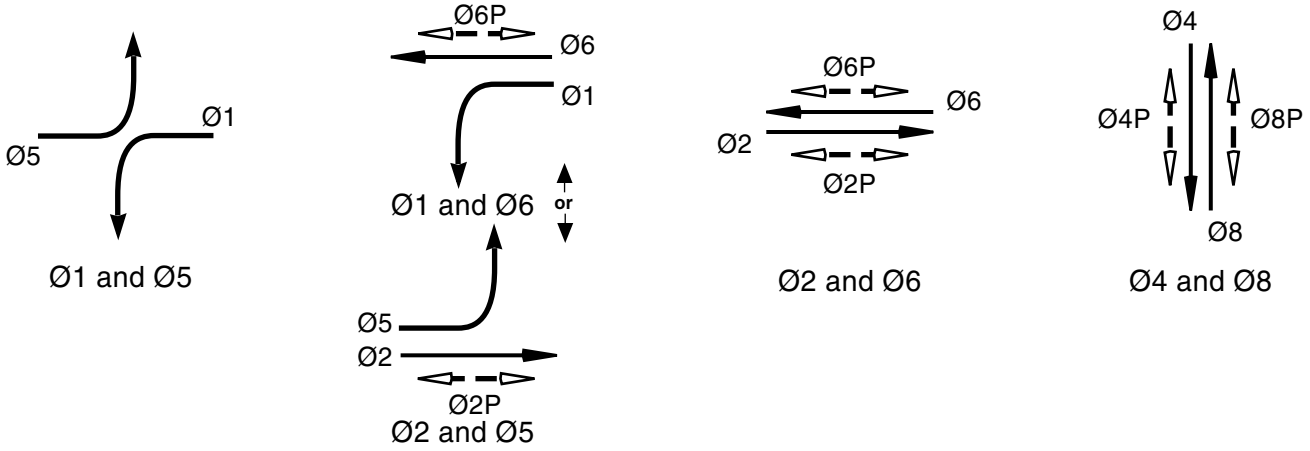
LEGEND:

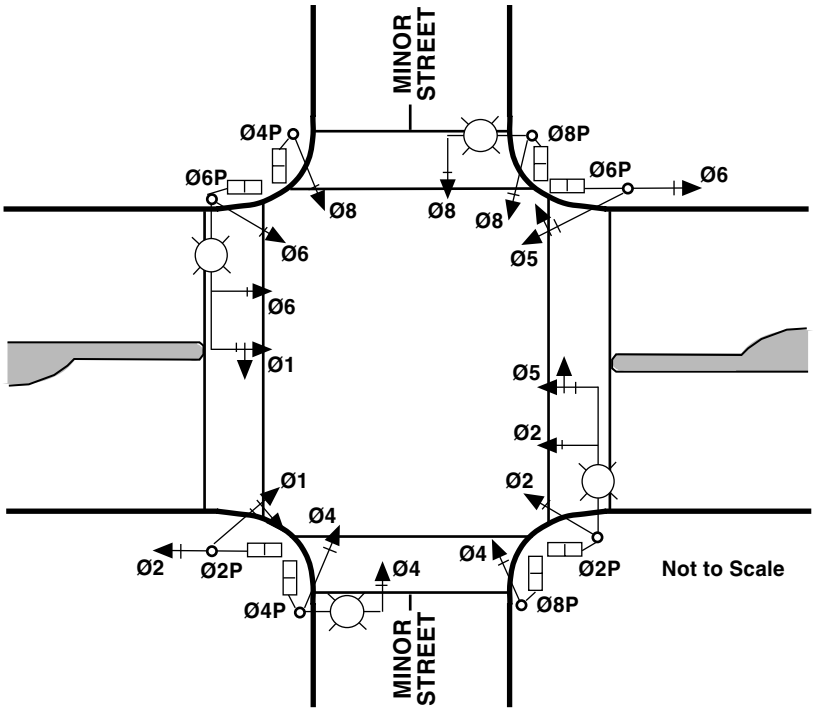


Signal face with arrow indications
Signal face with backplate
Pedestrian signal face
Standard with luminaire and signal mast arm

Figure 9-19
TYPICAL SIGNAL LAYOUT
(Five Phase "Dual Left" Operation)

Phase Diagram

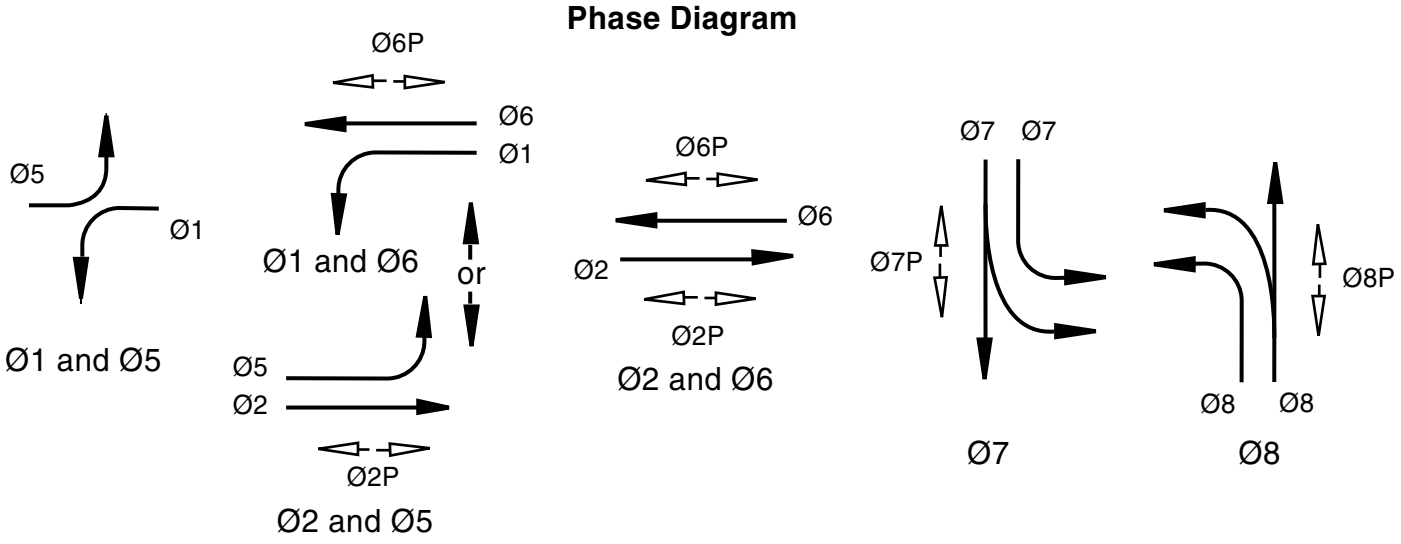


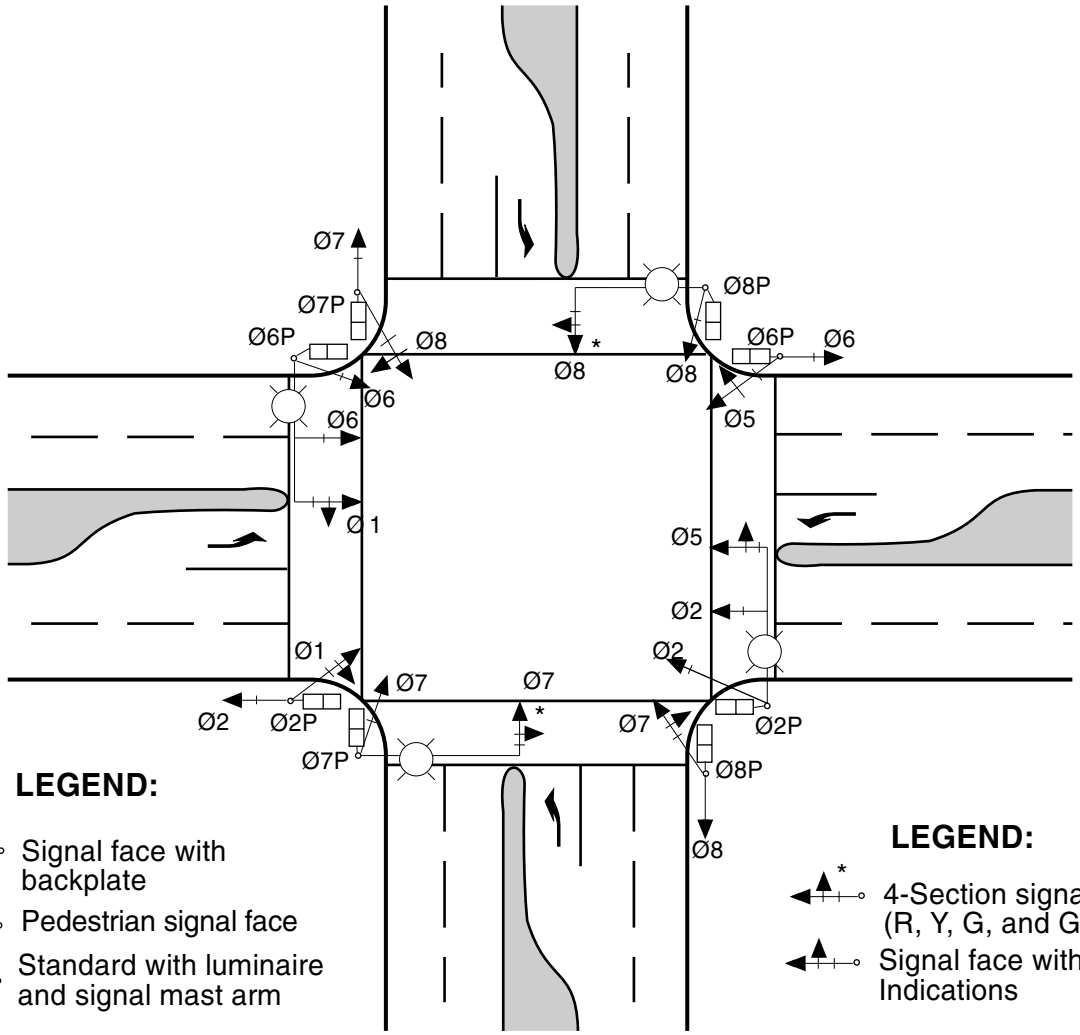


LEGEND:

- Signal face with arrow indications
- Signal face with backplate
- Pedestrian signal face
- Standard with luminaire and signal mast arm

Figure 9-20
TYPICAL SIGNAL LAYOUT
(Six Phase "Opposing" Operation)





LEGEND:

- Signal face with backplate
- Pedestrian signal face
- Standard with luminaire and signal mast arm

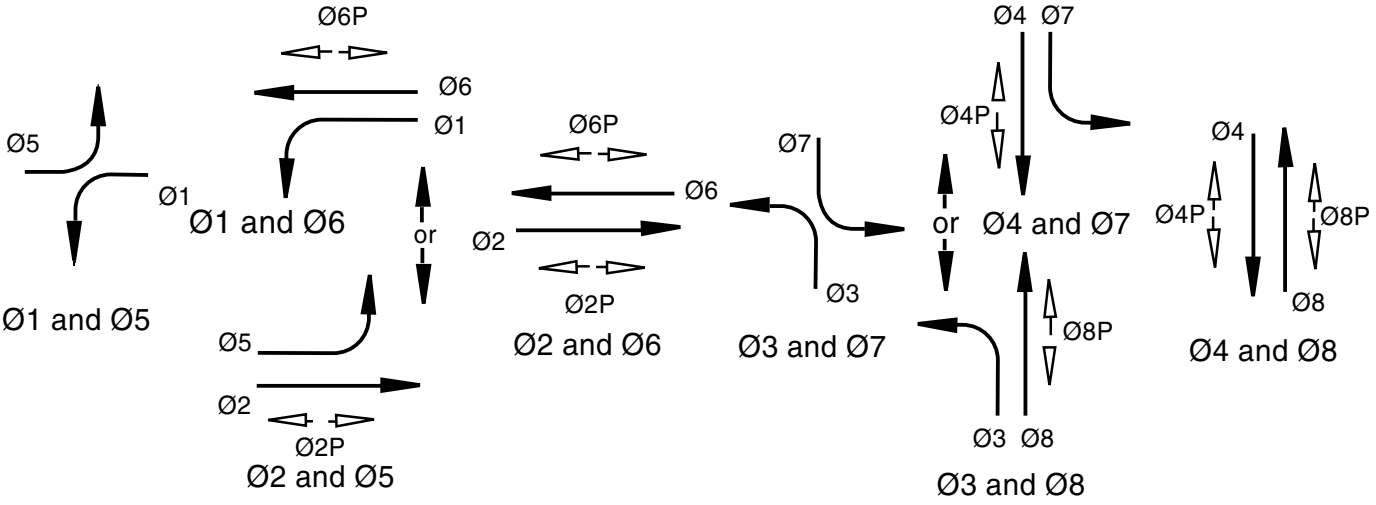
LEGEND:

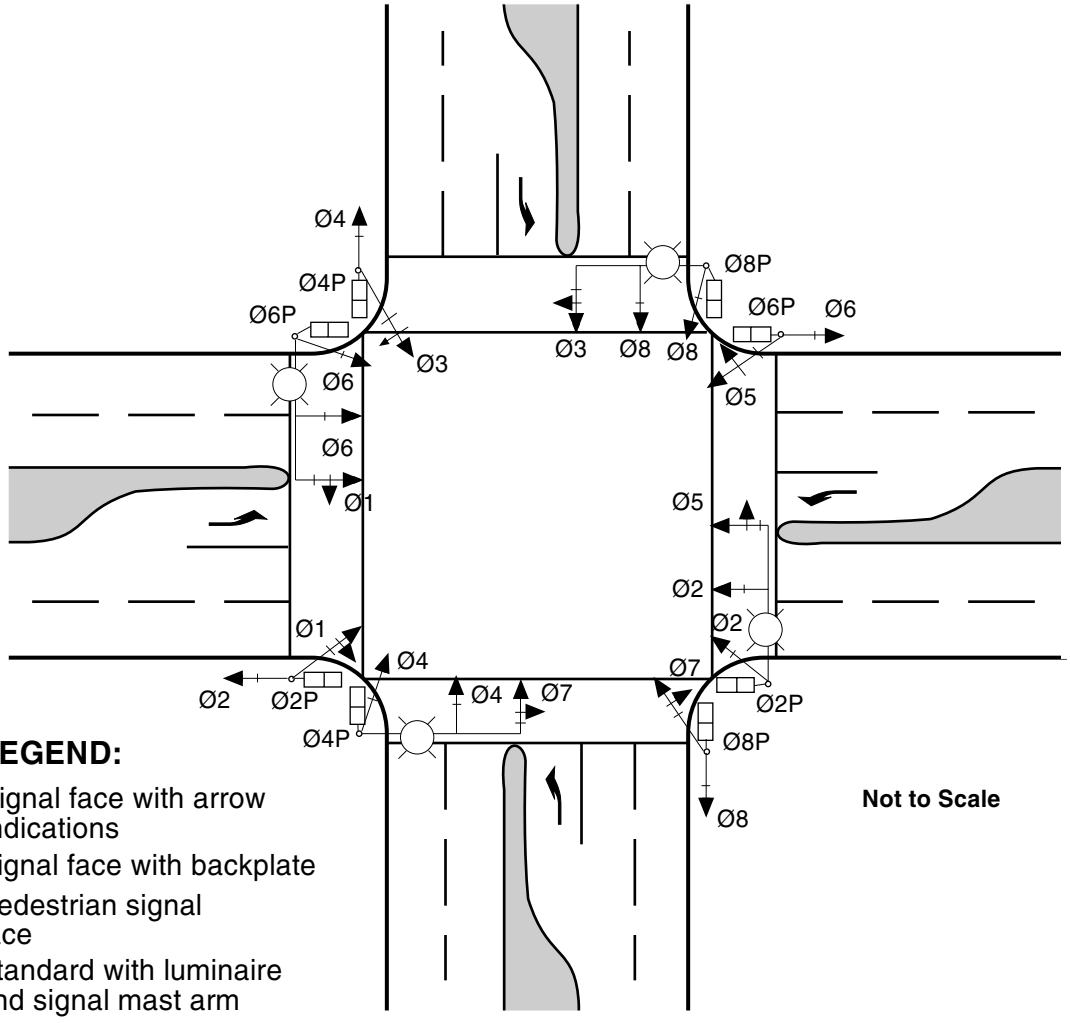
- * 4-Section signal face (R, Y, G, and GA)
- Signal face with arrow Indications

Not to Scale

Figure 9-21
TYPICAL SIGNAL LAYOUT
(Eight Phase "Quad Left" Operatin)

Phase Diagram



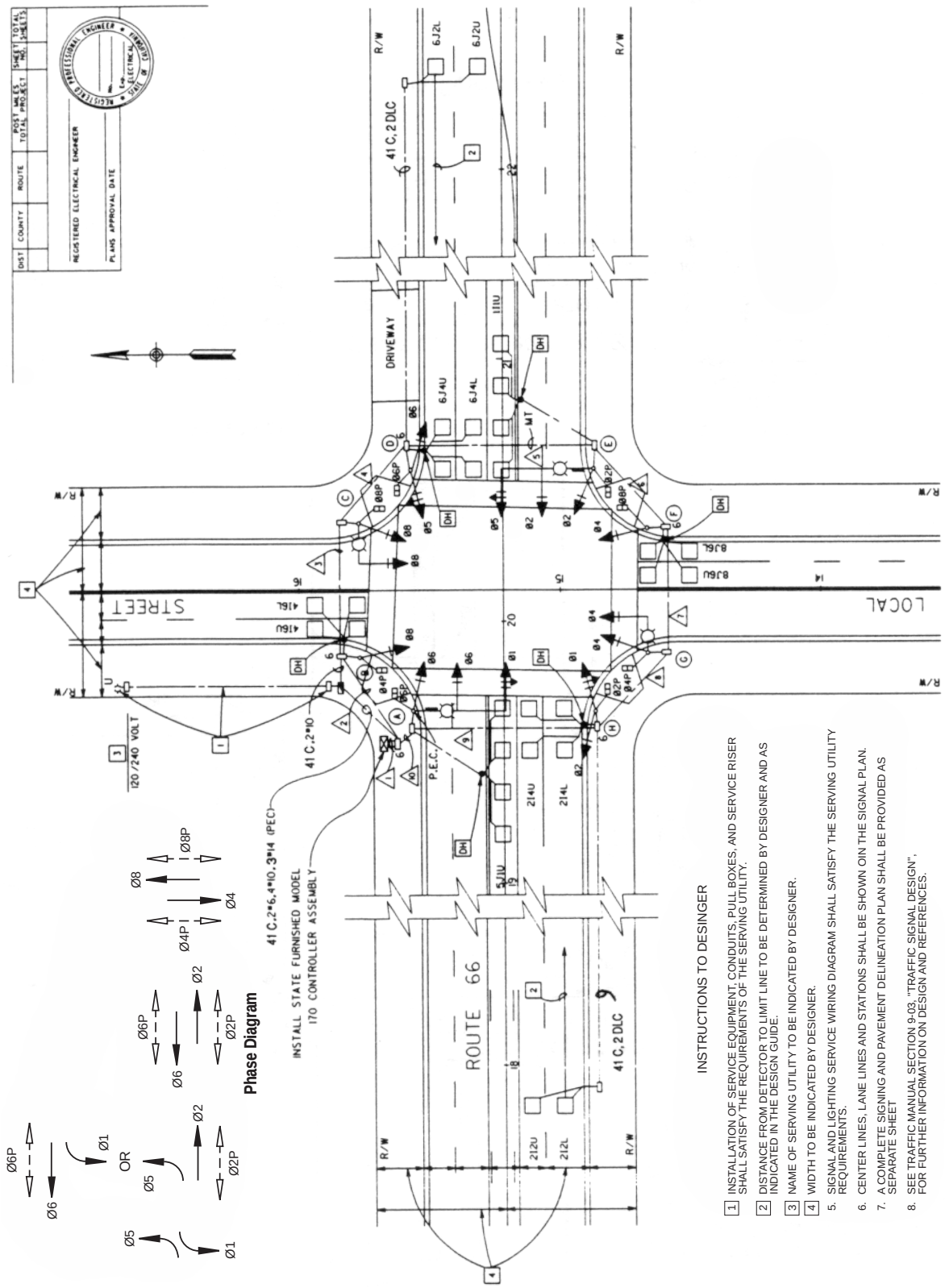


LEGEND:

- Signal face with arrow Indications
- Signal face with backplate
- Pedestrian signal face
- Standard with luminaire and signal mast arm

Not to Scale

Figure 9-22
TYPICAL TRAFFIC SIGNAL INSTALLATION



NOTE: This plan accurate for electrical work only.

Figure 9-23
POLE AND EQUIPMENT SCHEDULE

	STANDARD			VEH SIG MTG		PED. SIGNAL MTG	PPB		HPS LUMINAIRE	SPECIAL REQUIREMENTS
	TYPE	SIG M.A.	LUM M.A.	MAST	POLE		Ø	ARROW		
A	24-4-113	10.7m	3.7m	MAT MAS	SV-1-T	SP-1-T	4	←	200 W	IISNS "LOCAL STREET"
B	1A				TV-1-T	SP-1-T	6	→		
C	17E-1-113	4.6m	3.7m	MAS	SV-1-T	SP-1-T	6	←	200 W	
D	1A				TV-1-T	SP-1-T	8	→		
E	24-4-113	10.7m	3.7m	MAT MAS	SV-1-T	SP-1-T	8	←	200 W	IISNS "LOCAL STREET"
F	1A				TV-1-T	SP-1-T	2	→		
G	17E-1-113	4.6m	3.7m	MAS	SV-1-T	SP-1-T	2	←	200 W	
H	1A				TV-1-T	SP-1-T	4	→		

IISNS = INTERNALLY ILLUMINATED STREET NAME SIGN

Figure 9-24
CONDUCTOR AND CONDUIT SCHEDULE

AWG OR CABLE	CONDUCTOR RUN	1	2	3	4	5	6	7	8	9	10
# 14	Ø 1	3								3	3
	Ø 2	3					3	3	3	3	3
	Ø 4	3						3	3	3	3
	Ø 5	6	3	3	3		3	3	3	3	3
	Ø 6	6	3	3	3						3
	Ø 8	3	3	3							
	Ø 2P	2					2	2	2	2	2
	Ø 4P	4	2						2	2	2
	Ø 6P	4	2	2	2						2
	Ø 8P	4	2	2				2	2	2	2
	Ø 2PPB	1						1	1	1	1
	Ø 4PPB	1								1	1
	Ø 6PPB	1	1	1							
	Ø 8PPB	2	1	1	1		1	1	1	1	1
	PPB Common	2	1	1	1		1	1	1	1	1
	P.E.C.										3
	Spares	6	3	3	3		3	3	3	3	
	Total # 14	51	21	19	13		13	19	21	25	35
# 10	Intern. Illuminated Street Name Sign						2	2	2	2	2
	Luminaires			2			2	2	2	2	2
	Signal Common	2	1	1	1		1	1	1	1	1
	Total # 10	2	1	3	1		5	5	5	5	5
# 6	Signal Service	2									
Detector -Lead-in Cable	Ø 1 Detectors	1					1	1	1	1	1
	Ø 2 Detectors	4								4	4
	Ø 4 Detectors	2	2								
	Ø 5 Detectors	1									1
	Ø 6 Detectors	4	4	4	4						
	Ø 8 Detectors	2						2	2	2	2
	TOTAL DLC	14	6	4	4		1	3	3	7	8
	CONDUIT SIZE	2-78C	78C	63C	53C	78C	53C	63C	63C	78C	78C

Flashing Beacons 9-05

9-05.1 Introduction

Typical applications for flashing beacons include the following:

1. Signal Ahead
2. Stop Signs
3. Speed Limit Signs
4. Other Warning and Regulatory Signs
5. Schools
6. Fire Stations
7. Intersection Control
8. Freeway Bus Stops
9. At Intersections Where a More Visible Warning is Desired

A flashing beacon is one or more traffic signal sections with a flashing indication in each section. Because the effectiveness of flashing beacons has not been consistent from one location to another, the decision whether or not to install a flashing beacon should not be based solely upon the guidelines listed in this section.

Flashing beacons to be installed on a State highway shall conform to the following requirements:

1. Lenses should be 300 mm in diameter, except that lenses for flashing beacons at bus stops, stop sign flashing beacons, speed limit sign flashing beacons and beacons used in connection with ramp metering may be 200 mm in diameter.

2. A dimming device shall be used to reduce the brilliance of yellow flashing beacons during nighttime operation.

3. Two-section flashing yellow beacons may be connected to flash alternately or simultaneously.

9-05.2 Signal Ahead Flashing Beacons

Yellow flashing beacons may be used with SIGNAL AHEAD (W41) signs in advance of:

1. An isolated traffic signal on either a conventional highway or on an expressway in a rural area.

2. The first traffic signal approaching an urban area.

3. Any traffic signal with limited approach visibility, or where approach speeds exceed 80 km/h (50 mph).

9-05.3 Design

On divided highways where the median is 2.5 m wide, or greater, the installation may consist of:

1. Two Type 1 standards, each with a W41 sign and a 300 mm signal face, with one standard located in the median and the other off of the right shoulder; or

2. A Type 9 cantilever flashing beacon installation with a W41 or W41A sign and two 300 mm signal faces as shown in the Standard Plans.

The above installation designs may result in noncompliance with the Highway Design Manual mandatory standards for horizontal clearance and shoulder width, and the advisory design standard for

clear recovery zones. If such nonstandard features cannot be avoided, the designer must obtain approval in accordance with Topic 82 of the Highway Design Manual and the current instructions pertaining to exceptions from mandatory and advisory design standards.

On undivided highways or on highways where the median is less than 2.5 m wide, the installation may consist of a single standard located off of the right shoulder as described for use on divided highways, or it may be a Type 9 cantilever flashing beacon installation.

9-05.4 Financing

The cost of installing a Signal Ahead Flashing Beacon is normally included in the traffic signal project and the cost shared with the local agency. See Section 9-02.6.

9-05.5 Warning or Regulatory Sign Flashing Beacons

Flashing beacon shall be used only to supplement an appropriate warning or regulatory sign or marker.

Typical applications include:

1. Obstructions in or immediately adjacent to the roadway.

2. Supplemental to advance warning signs.

3. At mid-block crosswalks.

4. At intersections where a warning is appropriate.

The beacon should be operated only during those hours when the necessity for the warning or regulation exists.

9-05.6 Financing

The cost of installing a Warning or Regulatory Sign Flashing Beacon on a State highway shall be at 100% State expense.

9-05.7 Flashing Beacons at School Crosswalks

Flashing beacons at school crosswalks may be installed on State highways in accordance with Sections 21372 and 21373 of the California Vehicle Code. See Chapter 10 of this Manual for additional guidelines and also Section 9-02.6, Case I.

9-05.8 Speed Limit Sign Flashing Beacons

A Speed Limit Sign Flashing Beacon may be installed on a State highway for use in connection with a fixed or variable speed limit sign. The size and location of the circular yellow lenses are described in the MUTCD. When a Speed Limit Sign Flashing Beacon is installed at the request of a local agency, or installed by the local agency under a encroachment permit, the costs of installing and maintaining the beacon should be at 100% local agency expense.

9-05.9 Intersection Control Flashing Beacons

An Intersection Control Flashing Beacon consists of one or more signal sections, with a flashing circular yellow or circular red indication in each face. Application of Intersection Control Flashing Beacons shall be limited to:

1. Yellow indications on one route (normally the major roadway) and red indications for the remaining approaches; or

2. Red indications for all approaches.

New installations of overhead intersection control flashing beacons shall consist of red indications for each approach.

A stop sign shall be used on each approach with a flashing red indication.

Basic intersection lighting should be installed at intersections where an Intersection Control Flashing Beacon is to be installed.

9-05.10 Financing

The cost of installing an Intersection Control Flashing Beacon and intersection lighting shall be shared with the local agency in the same manner as a traffic signal. See Section 9-02.6.

9-05.11 Flashing Beacons for Fire Stations

Flashing beacons at fire station driveways or at intersections immediately adjacent to a fire station may be installed on State highways. The flashing beacon shall be used only to supplement an appropriate warning or regulatory sign. The flashing beacon shall be actuated from a non-illuminated condition by a switch at the fire station.

9-05.12 Financing

The costs of installing and maintaining the flashing beacon for the fire station shall be at 100% local agency or fire department expense.

9-05.13 Stop Sign Flashing Beacons

A Stop Sign Flashing Beacon consists of one or two signal sections with a flashing circular red indication in each section. The bottom of the housing of a Stop Sign Flashing Beacon shall be not less than 305 mm nor more than 610 mm above the top of the stop sign.

9-05.14 Financing

The cost of installing a Stop Sign Beacon shall be shared with the local agency in the same manner as a traffic signal. See Section 9-02.6.

9-05.15 Flashing Beacons at Bus Stops on Freeway Interchanges

At locations of approved bus stops within interchange areas, a flashing beacon may be provided near the top of a lighting standard to provide a flag stop.

9-05.16 Design and Operations

The following design and operational requirements shall be met:

1. A push button shall be provided on the lighting standard with a sign explaining the purpose and operation. The sign shall state that if no bus has arrived within 15 minutes (or other time) after the button has been actuated it will be necessary to actuate it again.

2. The flashing beacon shall consist of an 200 mm, signal section with an uncolored or white lens mounted on the lighting standard in such a position that it can be seen by an approaching bus driver on the freeway.

3. The operation of the control shall be such that the flashing beacon will operate for 15 minutes after the button has been actuated and then go out.

9-05.17 Financing

The costs of installing and maintaining Flashing Beacons at Bus Stops on Freeway Interchanges shall be at 100% State expense.

Highway Safety Lighting 9-06

9-06.1 Introduction

The purpose of highway safety lighting is to promote the safe and orderly movement of traffic by illuminating certain permanent features or conditions which are unusual, which require additional care and alertness to negotiate, and which, if illuminated, may be more readily comprehended and so compensated for by the motorist.

Freeway Lighting 9-07

9-07.1 General

On freeways, highway safety lighting should be installed at particular points in interchange areas. This lighting serves to illuminate areas of potential vehicle conflict and to delineate exit ramps, entrance ramps, and island noses.

Except where required by unusual freeway geometrics, lighting should not be installed unless the traffic volumes shown in Section 9-07.2 are met. The high standard of signing, markings, and delineation now being provided makes it possible in such situations to defer the installation of lighting facilities until required by increased traffic.

The use of high mast lighting systems may be considered where conventional lighting standards are difficult to maintain.

9-07.2 Warrants

1. ***Definitions.***

    a. Urban, Suburban and Rural Conditions. Urban conditions are considered to exist in those areas so designated on maps approved by the FHWA. Suburban conditions are considered to exist in those areas contiguous to the designated urban areas. Rural conditions exist in all other areas.

    b. ADT is the average daily traffic for up to five years after the freeway is opened to traffic.

    c. A surface street is any street other than a freeway. A local street is a surface street under the control of a local agency.

2. ***Freeway Interchange Safety Lighting.***

    Freeway Interchange safety lighting is considered to be warranted under either of the following conditions:

    a. Where the total sum of the ADT ramp traffic entering and leaving the freeway within the interchange area exceeds 5,000 under urban conditions, 3,000 under suburban conditions and 1,000 under rural conditions. The above figures refer to the total sum of the ADT for the normal four ramps at an interchange. Where the number of ramps connecting with the freeway is less than four, the above total sum of ADT may be reduced proportionately.

    b. Where the ADT on the freeway exceeds 25,000 for urban conditions, 20,000 for suburban conditions and 10,000 for rural conditions.

3. ***Freeway Ramp-Surface Street Intersection Safety Lighting.***

   Safety lighting at the intersection of a freeway ramp and a surface street is considered warranted if either of the conditions in 2a or 2b above are satisfied.

4. ***Lighting of Existing Local Streets Within the Limits of the Freeway Project.***

   Lighting of existing local streets within the limits of a freeway project, including lighting on local streets over or under the freeway, is considered warranted if:

   a. The local street is lighted to modern standards up to the freeway right of way and the local agency agrees to assume ownership and cost of maintenance; or

   b. The local street is not lighted to modern standards and the local agency agrees to assume ownership and all costs of installation and maintenance.

   If a local agency indicates that it proposes to install lighting on the local street within five years after construction is completed, the following should be installed on the project at 100% State expense:

   a. Conduit and other equipment in and under paved areas.

   b. Provisions for future structure lighting as stated in (7) below:

5. ***Lighting of New Local Streets within the Limits of the Freeway Project..***

   The installation of lighting on new local streets, including new frontage roads, that are constructed on new alignment for a local agency shall be governed by the following:

   a. Lighting may be installed when requested by the local agency, only if there is existing lighting in the area and if that lighting is owned by the local agency. The lighting design and financing shall follow the guidelines in Section 9-09.7.

   b. Where the existing lighting is owned by a private utility, only equipment that will be in or under paved areas shall be installed by the State. See Section 9-09.7.

   c. If no lighting exists in the area, new lighting shall be installed only if the local agency agrees to finance the installation and to assume the cost of ownership and maintenance.

6. ***Lighting for Exclusive Pedestrian Facilities.***

   The lighting for exclusive pedestrian facilities within the freeway project is considered warranted at the following locations:

   a. Separated walkways (not sidewalks) and crosswalks within the interchange areas.

   b. Bicycle paths at roadway crossings and at underpasses.

c. Bus stops within the interchange areas.

d. Pedestrian overcrossings and undercrossings.

Lighting shall be provided on pedestrian overcrossings and undercrossings where the local agency agrees to assume ownership and cost of maintenance.
Pedestrian undercrossings shall be provided with adequate daytime as well as nighttime illumination.

7. ***Freeway Structures Lighting.***

Lighting on or under a freeway structure is considered warranted if:

a. The lighting is for the purpose of illuminating acceleration lanes, deceleration lanes, weaving areas or walkways.

b. It is a part of local street lighting as stated in (4) or (5) above.

Provision for future lighting may be installed in structures for freeway illumination only if there is a definite requirement to install lighting as warranted above in the future. Provision for future lighting consists of conduit, pull boxes, anchor bolts and flush soffit luminaires.

8. ***Replacement of Lighting Owned by Other Agencies.***

See Section 9-09.7.

9. ***Lighting for Ramps at Rest Areas and Truck Inspection Stations.***

Lighting on freeway acceleration and deceleration lanes at rest areas and truck weight and inspection stations shall be considered in the same manner as interchange ramps.

Conventional Highway Lighting 9-08

9-08.1 General

On conventional highways, including expressways, State financing of highway safety lighting shall be limited to that at intersections with traffic signals or flashing beacons or at those locations which meet the conditions listed below. The existence of an intersection is not, in itself, a justification for lighting.

When highway safety lighting is to be installed at an intersection the "Basic" illumination as shown in Section 9-10.3 shall be provided.

9-08.2 Warrants

1. ***Existing Intersections.***

Safety lighting may be provided at existing intersections on expressways and conventional highways if one of the following conditions is fulfilled:

a. A Minimum Vehicular Volume, an Interruption of Continuous Traffic or Minimum Pedestrian Volume traffic signal warrant (see Section 9-01.2) is satisfied for any single hour which may be in darkness in winter months.

b. Four or more nighttime accidents in any recent consecutive 12-month interval or six or more nighttime accidents in any recent consecutive 24-month interval.

c. Where a traffic signal or an intersection flashing beacon is installed.

d. Where combinations of sight distance, or horizontal or vertical curvature of the roadway, channelization or other factors constitute a confusing or unsatisfactory condition that may be improved with lighting. The project report covering such lighting should include an explanation of the factors constituting the confusing or unsatisfactory condition.

2. ***New Intersections.***

Safety lighting may be provided at new intersections on expressways or conventional highways if there are indications that any of the warrants listed in 1(a) above will be fulfilled within five years after the opening of the project to traffic.

3. ***Railroad Grade Crossings.***

Safety lighting may be provided at railroad grade crossings where a substantial amount of railroad operation is conducted at night, particularly where train speeds are low, where crossings are blocked for long periods, or a study indicates that motorists experience difficulty in seeing trains or traffic control devices during the hours of darkness.

Highway Safety Lighting Development Procedures 9-09

9-09.1 General

General requirements for the development of lighting projects are noted in the Project Development Procedures Manual. The cost of lighting on Federal Aid highway projects is eligible for federal participation under certain conditions. The Federal Highway Administration uses "An Information Guide for Lighting Controlled Access Highways" published by the American Association of State Highway and Transportation Officials to determine eligibility for participation on Interstate projects.

The preparation of a Project Study Report may be required for lighting projects for scoping and programming purposes. The Project Development Procedures Manual and the appropriate Program Advisor should be consulted to determine specific reporting requirements.

9-09.2 Project Report

The following data are required to appraise the need for highway safety lighting installation and should be included in the Project Report:

1. ***Traffic Counts.***

Both pedestrian and vehicular traffic counts shall be shown for any single hour which may be in darkness in winter months. Traffic counts shall be shown on Forms TS-10A, B and/or C. On Form TS-11 the single hour traffic count shall be the one during a period of darkness which shows the most need for the project. Show pedestrian volume on each crosswalk for the same periods as the vehicular count.

2. ***Vehicle Speed.***

   The 85th percentile speed of vehicles on approaches to the intersection.

3. ***Electrical Service.***

   A statement as to the availability of electrical service. Where the establishment of electrical service is excessively costly due to line extension, consideration should be given to alternate sources of power or to deferment of the installation.

4. ***Other Data.***

   This includes:

   a. The location map;

   b. A condition diagram showing existing conditions;

   c. A summary of accidents and the collision diagram;

   d. Form TS-10A, B and/or C;

   e. Form TS-11;

   f. An improvement diagram showing existing and proposed lighting, channelization, and other proposed improvements. This may be combined with (b), (c), (d), and (e) on a single plan;

   g. An estimate of cost; and

   h. An explanation of the confusing or unsatisfactory conditions to be improved by the lighting.

9-09.3 Coordination With Utility Companies

During the design stage, the local electrical utility should be contacted to determine the location and type of service available.

9-09.4 Plans, Coordination and Processing

General requirements for the submittal of plans, specifications and estimates are noted in the Project Development Procedures Manual and the PS&E Guide. All electrical plans shall bear the following: "Note: This plan accurate for electrical work only."

The Office of Structures Design shall forward a reproducible general plan of all structures to the District Traffic Engineer or the District Electrical Design Section. The District shall submit two prints showing requirements for conduits, foundations, and pull boxes to the Office of Structures Design for review and comment. Locations of illuminated sign structures shall also be noted. One print of each plan will be returned to the District with any necessary changes indicated thereon. After any necessary changes have been made, the revised plans shall be signed and forwarded with the PS & E Report.

9-09.5 Financing

1. ***General Policy.***

   State participation in financing is based on the use of standard equipment in accordance with State plans and specifications. If local agencies desire to use more expensive equipment, the additional cost over the standard equipment shall be at 100% local agency expense except as noted below.

2. ***Freeways.***

The cost of installing highway safety lighting on freeways is to be at 100% State expense. If other agencies desire to provide lighting between interchange areas, such lighting may be included in the State's project. However, the State will not participate in installation costs. The State will maintain and operate the lighting at 100% local agency expense.

On Federal Aid projects, Federal participation will be requested when one or more of the traffic volume warrants in Section 9-07.2 are met.

At the intersections of freeway ramps with local streets, the installation cost of safety lighting shall be at 100% State expense if it is found to be warranted at any time within five years after the date the freeway is opened to traffic. Lighting, which meets the warrants stated in Section 9-07.2, may be installed at State expense on new frontage roads and local streets constructed as a part of a freeway project when such lighting will be owned by a local agency. Lighting design may conform to the established design standards of the local agency.

3. ***Existing Conventional Highway Intersections.***

Highway safety lighting to be installed at existing intersections shall be financed jointly by the State and the local agency in the same ratio as the number of legs under each jurisdiction bears to the total number of legs at the intersection.

On a small project, where the prorated share of the local agency is $3000 or less, the cost shall be at 100% State expense.

The District Director may approve the installation of warranted utility-owned safety lighting without submitting a Project Report to Headquarters.

Normally, the monthly charges for utility-owned safety lighting installed at the request of the State should be shared jointly with the local agency, as above.

4. ***New Conventional Highway Intersections.***

The installation cost of highway safety lighting at new intersections on a State highway as a result of a State highway project shall be at 100% State expense. The installation cost of highway safety lighting at new intersections on a State highway as a result of a local agency project shall be at 100% local agency expense.

5. ***Railroad Crossings.***

The costs of installing and maintaining safety lighting at railroad grade crossings on State highways shall be at 100% State expense.

9-09.6 Lighting by Local Agencies or Others

Where a local agency proposes to install lighting on a State highway, an encroachment permit is required. Lighting may also be installed at the intersection of a State highway and private driveway by a private property owner under an encroachment permit. Such lighting shall in no way detract from the effectiveness of existing State safety lighting or in any way interfere with the safe movement of

traffic. On existing roadways, except expressways or freeways, the lighting may be installed on wood poles with overhead wiring. On expressways and full freeways, the equipment shall meet State standards, i.e., steel standards and underground wiring. Where a local agency proposes to install continuous lighting using luminaires of higher light output than the existing highway safety luminaires, the project should include replacing the existing units with new luminaires with the higher light output. The State will review the design of such lighting. The installation may be performed by local agency forces, a contractor or an electrical utility.

The State will participate only in the costs of installation or upgrading, maintenance, and operation of safety lighting as warranted in Sections 9-07.2 and 9-08.2.

9-09.7 Reconstruction of Existing Facilities

1. ***Freeways***

When affected by State freeway construction, existing street lighting facilities owned by a local agency shall be replaced in kind, as nearly as possible, at 100% State expense using salvaged material where feasible.

In the event the local agency desires to have the relocated local agency owned lighting system reconstructed to an improved standard as part of a State contract, the difference in cost between replacement in kind and the construction requested shall be estimated and the agency shall agree to reimburse the State for the additional cost.

The reconstruction of existing street lighting facilities owned by a private utility is the responsibility of the utility and will be handled by the Division of Right of Way. See Section 9-07.2(5b).

2. ***Conventional Highways***

When affected by construction on a conventional State highway, existing street lighting facilities owned by a city, county, or lighting district shall be reconstructed at the sole expense of the owner unless prior rights can be established.

In the event a local agency desires to have an existing continuous lighting system along a State highway reconstructed to an improved standard, or a new system built to higher than State standards, the cost to the State shall be limited to its share of the lighting at those locations where safety lighting is warranted.

Highway Safety Lighting Design Standards 9-10

9-10.1 General

The design of highway safety lighting by the California Department of Transportation (Caltrans) is based upon the following publications:

1. Traffic Manual (Caltrans)
2. Standard Specifications (Caltrans)
3. Standard Plans (Caltrans)
4. Signal and Lighting Design Guide (Caltrans)

9-10.2 Freeway Ramps and Connections

A minimum of two luminaires should be placed at each freeway exit ramp and one luminaire at each freeway entrance ramp. Typical locations are shown in Figures 9-25 and 9-26. Typical locations for luminaires at the intersections of freeway ramps and surface streets are shown in Figure 9-26.

One or more additional luminaires may be installed when justified by geometrics, traffic patterns, background ambient lighting and/or freeway ramp traffic volumes. Additional lighting may be installed if ramp traffic meets the following volumes during one hour of darkness:

	Exit Ramp		*Entrance Ramp*	
Freeway ADT	***Volume***	***Ltg.***	***Volume***	***Ltg.***
>75,000	>300 vph	+ 1	>300 vph	+ 1
>150,000	>700 vph	+ 2	>700 vph	+ 2

9-10.3 Conventional Highways

Where highway safety lighting is to be installed at intersections on conventional highways,(including the intersection of a freeway ramp with a local street), the minimum maintained horizontal illuminance should be as follows:

In urban areas and expressways, 1.6 horizontal lux on the area normally bounded by the crosswalks, and 6.5 horizontal lux at the intersection of centerlines of the entering streets.

In rural areas, 1.1 horizontal lux on the area normally bounded by the crosswalks, and 3.2 horizontal lux at the intersection of centerlines of the entering streets.

Electroliers at conventional highway intersections should be located as shown in Figures 9-27 and 9-28.

To determine the position and number of luminaires needed to provide a desired lighting level or to determine the lighting level achieved by a given pattern of luminaires, the isolux diagram for the luminaire may be used. The lighting level at any point may be approximated by adding the values shown by the isolux curve passing through the point from each contributing luminaire.

Isolux diagrams for the commonly used luminaires are shown in the Standard Plans. These diagrams represent the minimum acceptable values and therefore are appropriate for use with any particular manufacturer's luminaire. Transparancies of these diagrams in various scales are available to facilitate their use. Since these diagrams are based on initial values, a light depreciation factor must be applied to determine the maintained level of lighting.

9-10.4 Sign Lighting

Some overhead directional signs are illuminated. The sign lighting equipment and installation details are shown in the Standard Plans.

9-10.5 Tunnel Lighting

Tunnels should have sufficient illumination during the day so that vehicles inside the tunnel may be seen by approaching motorists. All interior walls and ceilings of tunnels to be lighted should be

painted or tiled in a light color. All concrete surfaces to be painted should have a Class 1 finish.

Tunnels over 90 m long may require lighting in the daytime.

Tunnels 30 m to 90 m long normally do not require daytime lighting but interior walls and ceiling should be painted. Conventional night lighting should be installed.

9-10.6 Falsework Lighting

Lighting should be considered for all passageways including pedestrian openings through or under falsework. The faces of all falsework and forms located within or adjacent to the traveled way should be illuminated on the approach sides during the hours of darkness.

9-10.7 Bus Stop Lighting

At locations in the interchange area where a special ramp for buses and a bus stop are provided, a minimum of one luminaire should be provided at the bus stop and at each crosswalk on the freeway ramp.

9-10.8 Park-and-Ride Lot Lighting

Lighting of Park-and-Ride Lots is desirable, not mandatory. There may be several legitimate reasons why lighting is not provided, e.g., in a rural area where line extension charges would be excessive. The following guidelines should be used in determining the amount of lighting to be installed where it has been determined that we can provide lighting without excessive cost:

1. Use lighting units on utility-owned poles whenever possible.

2. Design the lighting to provide 0.6 lux (minimum) in the darkest area of the facility.

3. Keep the number of poles and fixtures to the minimum necessary to meet the 0.6 lux level.

4. Design for all-night illumination.

Lighting Standards 9-11

9-11.1 General

Lighting standards for installation on State highways will normally be one of the types shown in the Standard Plans. The exception is where a local public agency uses different lighting standards and (a) has existing lighting that is being replaced due to State highway construction, or (b) desires the inclusion of their roadway lighting into a State highway project. (See Sections 9-09.2 and 9-09.5 for policy and financing.) Details for each type of lighting standard are shown in the Standard Plans.

9-11.2 Types, Application and Mast Arm Lengths

Types 15 and 22 standards are used on conventional highways and expressways. Also, they may be used at the intersection of freeway ramps with surface streets. The Type 15 may be used on structures in lieu of a Type 21 standard where a lower mounting height is desired. The mast arm length normally used is 3.7 m, but lengths of 1.8 m, 2.4 m, 3.1 m and 4.6 m are available.

The Type 21 standard is used on structures and may be mounted on the barrier railing, on the structure deck or on a retaining wall. The mast arm length normally used is 3.7 m. Lengths of 1.8 m, 2.4 m, 3.1 m, or 4.6 m are available.

Types 30, 31, and 32 standards are used on freeways and in freeway interchange areas. The Type 30 is used where the standard cannot be located further than 5.5 m from the edge of the traveled way. Normal mast arm length is 4.6 m and lengths of 1.8 m, 2.4 m, 3.1 m and 3.7 m are available. The Type 31 is available only with a 6.1 m mast arm and should be located a minimum of 6 m from the edge of the traveled way. The Type 32 is available only with a 9.1 m mast arm and without a slip base, and should be located a minimum of 9 m from the edge of the traveled way.

9-11.3 Foundations

Foundation details and foundation installation details for each lighting standard are shown in the Standard Plans.

Location of foundations shall be as follows:

1. ***Lateral (Set Back).***

   In general, lighting standards should normally be set as far from the right or left edge of the pavement as conditions permit. Exceptions to this occur in cut or fill sections with slopes steeper than 1:4; foundation locations for these conditions are shown in the Standard Plans. On curved ramps, lighting standards should be located on the inside of the curve.

2. ***Longitudinal.***

   a. Normal spacing for Types 21, 22, 30, 31 and 32 standards is 55 m. Normal spacing for Type 15 is 46 m.

   b. Typical locations for standards are shown in Figures 9-25 through 9-28.

3. ***Structures.***

   On structures and retaining walls, lighting standards should be located at least 1.5 m from the structure expansion joints or hinges. Care should be taken in locating electroliers on lower roadways or structures so as not to be a glare source to vehicles on a higher structure.

9-11.4 Slip Bases

Slip bases shall be used under Types 30 and 31 standards and under Type 15 standards on freeways, expressways and conventional highways where speeds are in excess of 64 km/h. Exceptions to this policy are that slip bases are not used under lighting standards upon which signals are mounted or under lighting standards located:

a. On or behind structures, retaining walls or barrier railing;

b. In sidewalk areas;

c. Behind guardrail;

d. More than 9 m from traveled way; or

e. Where pedestrians would be close enough to be endangered by a pole knockdown.

Luminaires 9-12

9-12.1 General

Normally, the luminaire for a new installation of safety lighting on State highways is a full-cutoff type using a high pressure sodium lamp.

9-12.2 Roadway Luminaires

On freeways, 200-watt lamps shall be used with 9.14 m mounting heights and 310-watt lamps shall be used with 12.19 m mounting heights. On conventional highways and at the intersections of freeway ramps with surface streets, 150-watt lamps shall be used with 9.14 m mounting heights.

Utility owned semi-cutoff type luminaires should be provided with glare shields in rural areas.

9-12.3 Soffit Luminaires

Soffit luminaires are special fixtures either suspended from or flush-mounted into structures to illuminate the roadway under the structure. They shall be used with 70 or 100 watt high-pressure sodium lamps, depending upon lighting requirements. Normally, the fixtures should not be located over the traveled way on freeways.

9-12.4 Wall Luminaires

Wall luminaires are fixtures designed to be surface mounted on vertical surfaces. However, a simple right angle bracket permits mounting them from a horizontal surface such as the bottom slab of a box girder. They are used with the same lamps as soffit luminaires.

Figure 9-25
FREEWAY LIGHTING

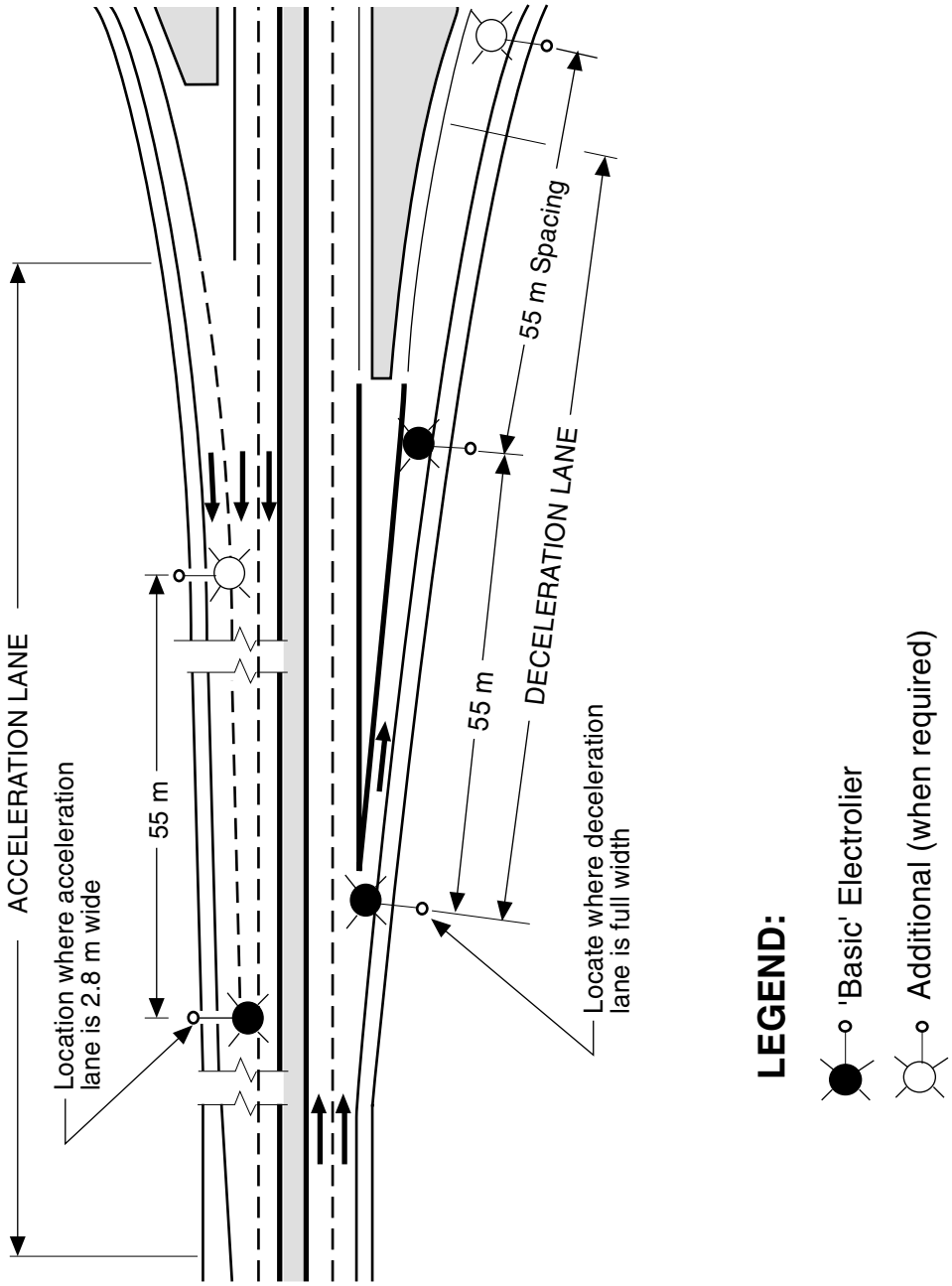
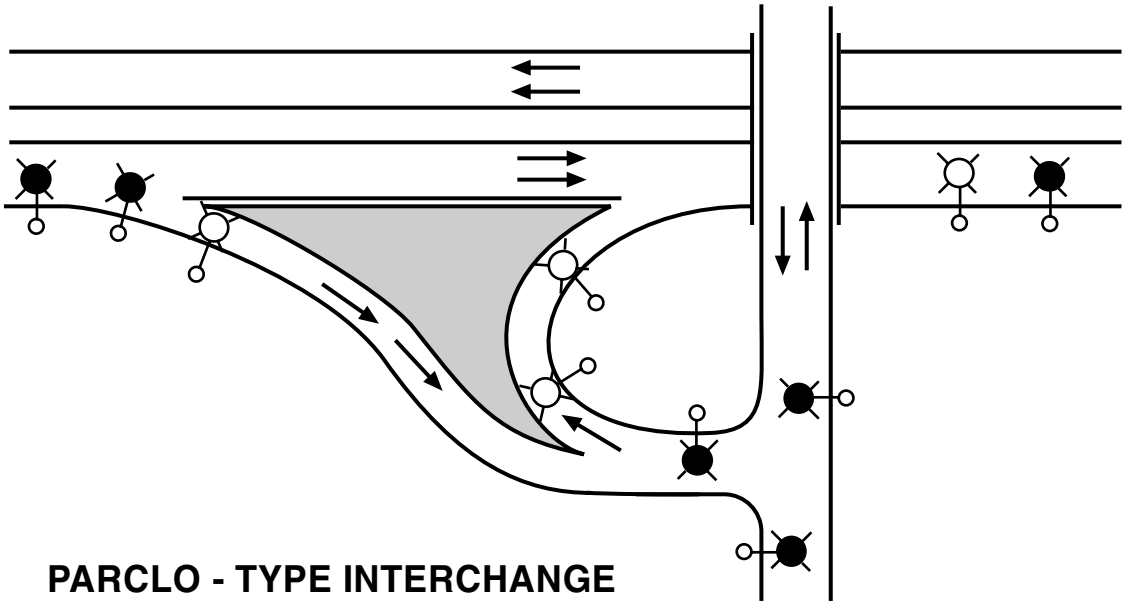
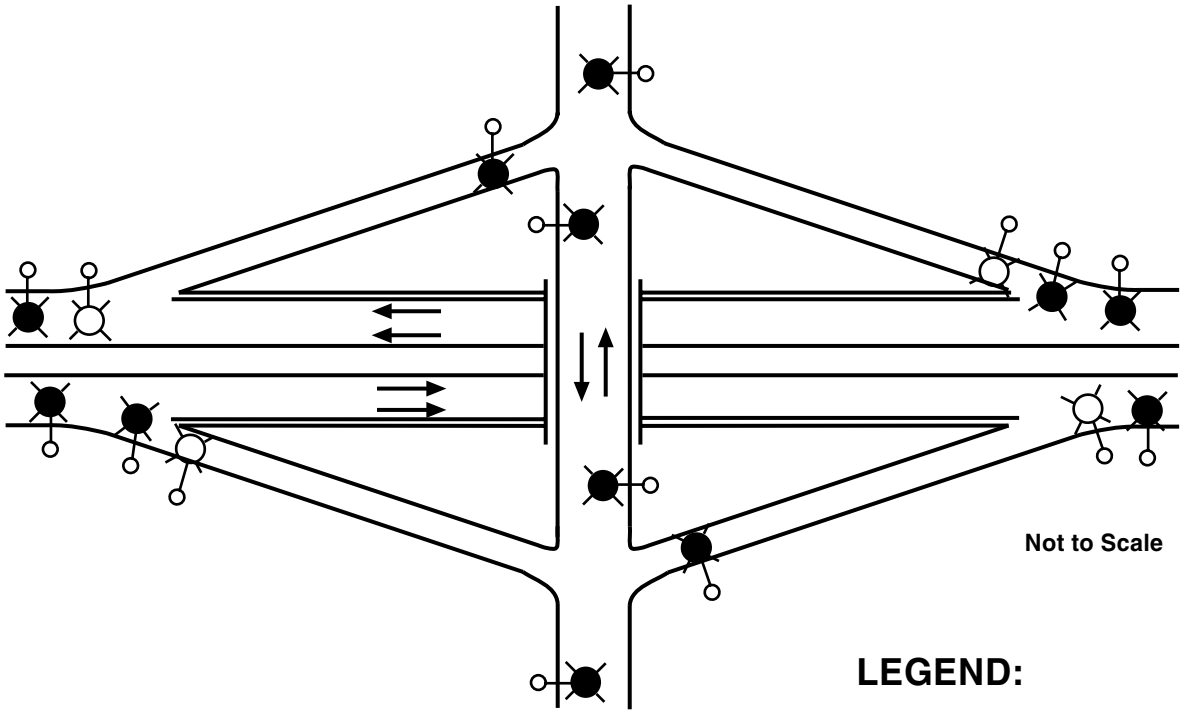


Figure 9-26
FREEWAY LIGHTING



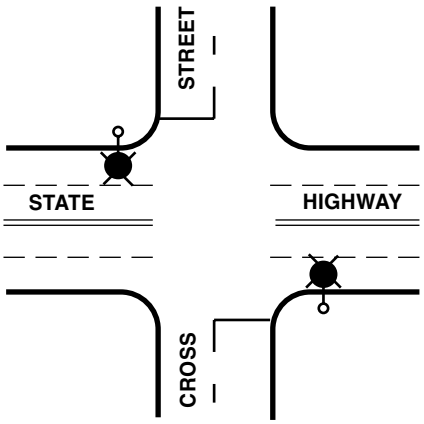
PARCLO - TYPE INTERCHANGE



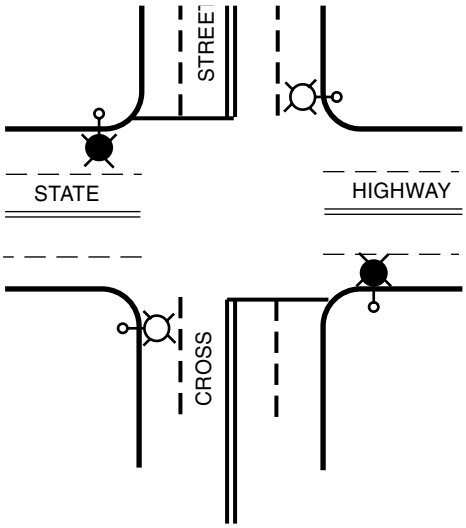
DIAMOND INTERCHANGE

Figure 9-27
INTERSECTION LIGHTING

INTERSECTION WITH 2-LANE STREET

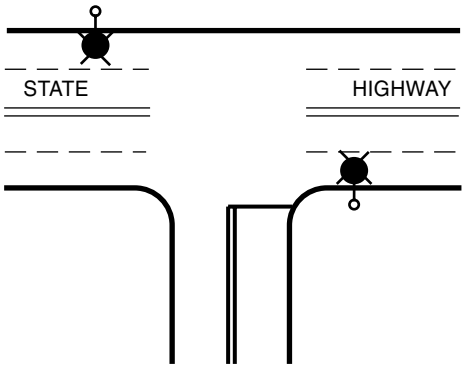


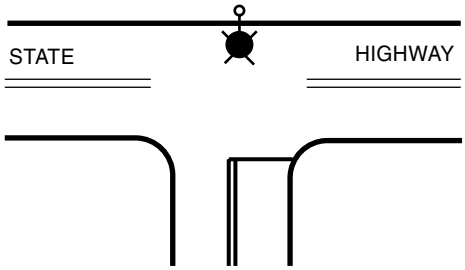
INTERSECTION WITH 4-LANE STREET



Not to Scale

TEE INTERSECTIONS



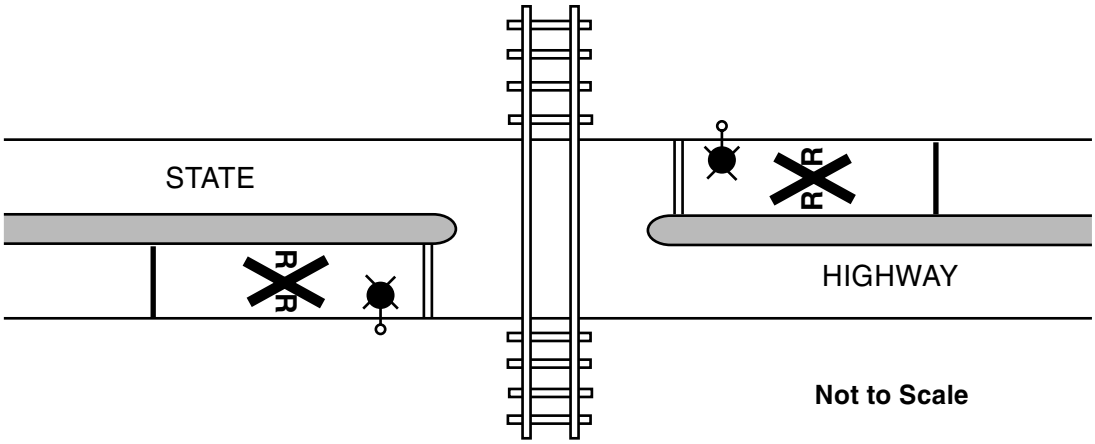


Not to Scale

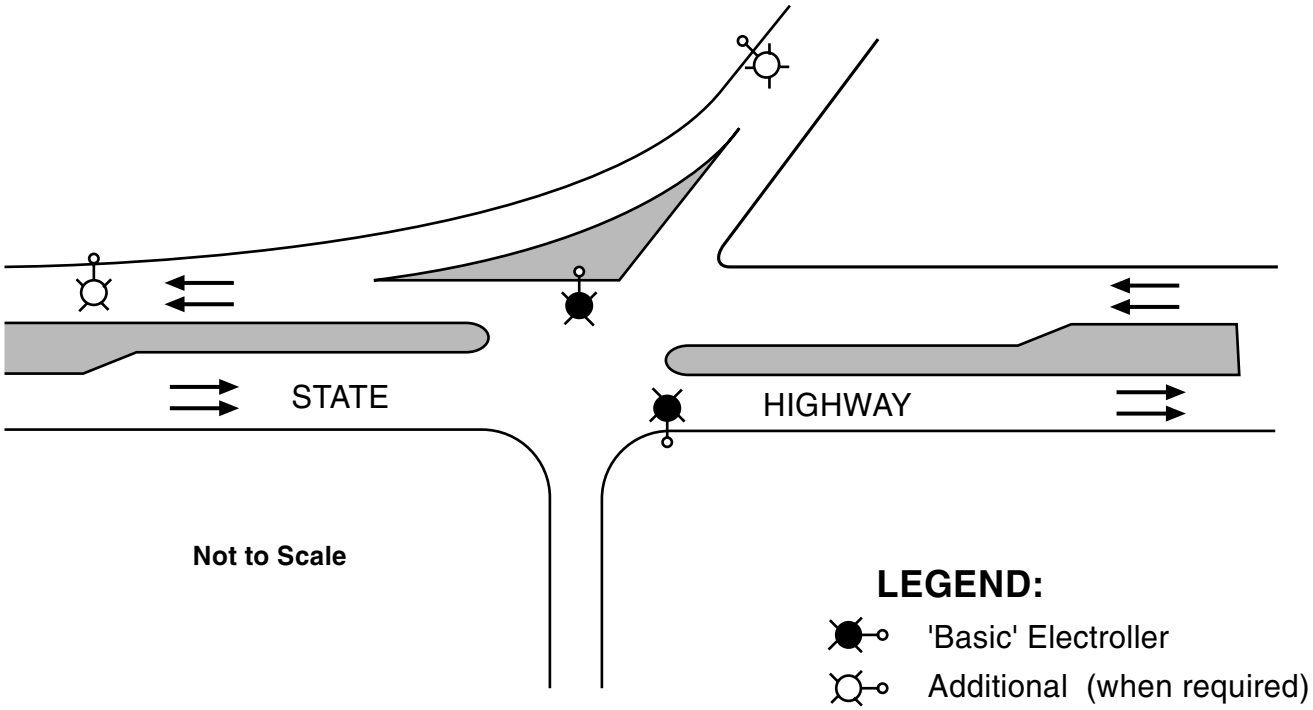
LEGEND:

'Basic' Electroller
Additional (when required)

Figure 9-28
INTERSECTION LIGHTING



RAILROAD CROSSING



DIVIDED HIGHWAY

Conduit, Wiring and Circuits 9-13

9-13.1 Introduction

The design of a traffic signal or highway safety lighting system should provide adequate capacity, both in wire size and conduit size, for the proper operation of the complete system. In addition, it is important to include adequate capacity in the electrical system to allow maintenance to make repairs safely and promptly. One example of this is the spare conductors that are provided in major conduit runs for a traffic signal.

9-13.2 Conduit

Installation of conduit shall conform to the requirements of the Standard Specifications.

9-13.3 Types of Conduit

The types of conduit most often used in traffic signal and highway safety lighting circuits are:

1. Rigid steel conduit.

2. Rigid steel conduit that has been coated with polyvinyl chloride or polyethylene.

3. Rigid nonmetallic conduit. Normally, this is Schedule 40 PVC conduit for underground installations and Schedule 80 PVC for above ground installations.

4. Liquid tight flexible metal conduit.

5. Intermediate steel conduit.

6. Flexible nonmetallic conduit.

9-13.4 Conduit Size

The minimum size of conduits for various applications should be as follows:

1. Traffic Signal installations:

a.	Roadway Crossings	53C
b.	Detector	41C
c.	Signal Standard to Pull Box	53C
d.	Controller Cabinet to Pull Box	(2)78C
e.	Service Cabinet to Pull Box	41C
f.	Interconnect	41C

2. Highway Lighting:

a.	Pull Box to Pull Box	41C
b.	Light Standard to Pull Box	41C
c.	Soffit Light to Pull Box	35C
d.	Service Cabinet to Pull Box	41C

9-13.5 Conduit Fill

The National Electrical Code limits the portion of the conduit's cross section that can be occupied by conductors to the following:

One Conductor	53%
Two Conductors	31%
Three or More Conductors	40%

However, for traffic signal installations, the conduit fill for new conduit should be limited to 26% and for existing conduit should be limited to 35%. This will compensate for the large number of conductors, the length of the run and the number of bends. Table 9-8 shows the cross-sectional areas of the conduits commonly used in traffic signal installations.

9-13.6 Conduit on Structures

Conduits should be run either parallel to or at right angles to the structure girders. A variation of ±15 degrees is acceptable.

Except for sidewalk joints, a conduit expansion fitting should be installed at each structure joint, hinge or abutment where a longitudinal movement of 12 mm or greater may occur. Where a lateral movement of 6 mm or greater may occur, an expansion-deflection fitting should be installed. Details for placement of expansion fittings and expansion-deflection fittings are shown in the Standard Plans.

9-13.7 Pull Boxes

Pull boxes should be installed to limit the length of conductor pull, to provide a point where conduits can be branched and/or conductors can be spliced and to simplify access to standards, poles and cabinets.

9-13.8 Installation of Pull Boxes

Pull Boxes should be installed:

1. At 60 m, or less, spacing in conduit runs;
2. At locations where conduits branch;
3. Adjacent to the foundation for each signal standard, lighting standard, illuminated sign, controller cabinet or service cabinet; and
4. At the toe of slope or at the hinge point when placed on a slope.

Pull boxes should not be installed in the traveled way if it can be avoided. When it is necessary to install them in the traveled way, the box, cover and foundation should be capable of supporting heavy wheel loading.

9-13.9 Pull Box Size

The minimum size of pull boxes for various applications should be as follows:

1. Signal or Lighting Conduits	No. 5
2. Adjacent to Signal or Lighting Standards	No. 5
3. Adjacent to Controller Cabinet	No. 6
4. Adjacent to Service Cabinet	No. 5
5. Detector Termination	No. 5
6. With 4, or more, Conduits	No. 6
7. Telephone Conduits	No. 5

Pull boxes with transformers should be provided with extensions.

9-13.10 Wiring

The dimensions of conductors normally used in traffic signal and highway lighting circuits are shown in Table 9-9. The values shown in the table may be used to calculate conduit fill.

9-13.11 Voltage Drop

The conductors between the service point and the load (lamps, ballasts, controller cabinets, etc.) should be sized to limit the voltage drop to less than 5%.

The resistance (ohms per 1,000 m) of conductors commonly used in traffic signal and highway lighting circuits is shown in Table 9-9. The values shown are based on an ambient temperature of 75° C.

Voltage drop can be calculated using:

Volts Drop = 2ILR

Where: I = Current
L = Length of Conductor
R = Resistance of Conductor (1,000 m)

If the voltage drop is known, the following formula can be used to determine the minimum conductor size:

R = Volts Drop ÷ 2IL

Example: The allowable voltage drop for a 380 m run feeding a 6.5 ampere load is 12 volts.

R = 12 ÷ (2) (6.5) (.38) = 2.43

From Table 9-9, the minimum wire size is No. 6.

9-13.12 Circuit Voltages

Traffic signal and flashing beacon control equipment normally is designed to operate on a 120-volt AC circuit.

A 120-volt or 240-volt circuit is normally used for highway lighting circuits. For very large lighting circuits, a 480-volt circuit may be required.

Table 9-8
AVAILABLE CONDUIT AREA
(Square Millimeters)

CONDUIT SIZE	PERCENT OF FILL				
	26%	35%	40%	50%	100%
35	145	194	220	277	555
41	340	460	526	658	1316
53	563	759	867	1084	2168
63	803	1081	1236	1545	3090
78	1237	1666	1904	2380	4761
91	1661	2235	2554	3193	6387
103	2134	2872	3282	4103	8206

As a practical limit, projects for new installations should be designed to the 26% fill limitation.

Table 9-9
CONDUCTOR SIZE

CONDUCTOR SIZE (AWG)	TYPES TW, THW, USE, RHH & RHN		D.C. RESISTANCE ohms/1000 m
	INSULATION THICKNESS (mm)	TOTAL AREA (mm^2)	
#14	1.14	14	10.07
#12	1.14	16	6.33
#10	1.14	20	3.97
#8 Stranded	1.5	40	2.56
#6 Stranded	1.5	53	1.61
#4 Stranded	1.5	70	1.02
#2 Stranded	1.5	95	0.62
Type B Loop Detector Lead-in Cable (DLC)		47	
Type C Loop Detector Lead-in Cable (DLC)		42	
Magnetometer Detector Lead-in Cable (MLC)		32	
Signal Interconnect Cable (3-Pair)		60	
Signal Interconnect Cable (6-Pair)		117	